AD-A071 359 ARMY AEROMEDICAL RESEARCH LAB FORT RUCKER AL F/G 5/8

HEAD AIMING/TRACKING ACCURACY IN A HELICOPTER ENVIRONMENT.(U)

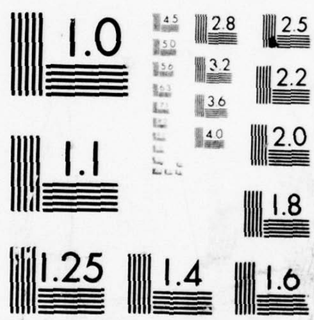
MAY 79 R W VERONA, J C JOHNSON, H D JONES

UNCLASSIFIED USAARL-79-9 NL

| OF |

AD
A071359

END
DATE
FILMED
8-79
DDC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

LEVEL III

(12)

B.S.

USAARL REPORT NO. 79-9

HEAD AIMING/TRACKING ACCURACY IN A HELICOPTER ENVIRONMENT

Final Report

By

Robert W. Verona

John C. Johnson

Heber Jones

HUMAN TOLERANCE AND SURVIVABILITY DIVISION

Sensory Physiology

MAY 1979

U.S. ARMY AEROMEDICAL RESEARCH LABORATORY

FORT RUCKER, ALABAMA 36362

USAARL

NOTICE

Qualified Requesters

Qualified requesters may obtain copies from the Defense Documentation Center (DDC), Cameron Station, Alexandria, Virginia. Orders will be expedited if placed through the librarian or other person designated to request documents from DDC.

Change of Address

Organizations receiving reports from the US Army Aeromedical Research Laboratory on automatic mailing lists should confirm correct address when corresponding about laboratory reports.

Disposition

Destroy this report when it is no longer needed. Do not return it to the originator.

Disclaimer

The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy, or decision, unless so designated by other official documentation. Citation of trade names in this report does not constitute an official Department of the Army endorsement or approval of the use of such commercial items.

Reviewed:

Roger W. Wiley

Roger W. Wiley, MAJ, MSC
Director, Human Tolerance and
Survivability Division

David D Glick

David D. Glick, MAJ, MSC
Chairman, Scientific Review
Committee

Released for Publication:

Stanley C. Knapp

STANLEY C. KNAPP
Colonel, MC
Commanding

(14) USAARL-79-9

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE

READ INSTRUCTIONS BEFORE COMPLETING FORM

1. REPORT NUMBER
USAARL Report No. 79-9

2. GOVT ACCESSION NO.

3. RECIPIENT'S CATALOG NUMBER

4. TITLE (and Subtitle)
(6) HEAD AIMING/TRACKING ACCURACY IN A HELICOPTER ENVIRONMENT.

AO58444

5. TYPE OF REPORT & PERIOD COVERED
(9) Final rept.

6. PERFORMING ORG. REPORT NUMBER

7. AUTHOR(s)
(10) Robert W. Verona
John C. Johnson
Heber D. Jones

8. CONTRACT OR GRANT NUMBER(s)

9. PERFORMING ORGANIZATION NAME AND ADDRESS
Human Tolerance and Survivability Division
US Army Aeromedical Research Laboratory
Fort Rucker, Alabama 36362

10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
6.11.01.A, 3A161101A91C,288
6.42.07.A, 4E464207D425

11. CONTROLLING OFFICE NAME AND ADDRESS
US Army Medical Research and Development Command
Fort Detrick
Frederick, Maryland 21701

12. REPORT DATE
(11) May [redacted]79

(12) 86p.

13. NUMBER OF PAGES
84

14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)
(16) 3A161101A91C, 4E464207D425

15. SECURITY CLASS. (of this report)
Unclassified

15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release; distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)
- head aiming
- head tracking
- helmet displays
- visually coupled systems
- aircraft helmets
- eye/dominance
- helmet weighting

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

See reverse.

DD FORM 1 JAN 73 1473 EDITION OF 1 NOV 65 IS OBSOLETE

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

404 578

JB

20. ABSTRACT:

This experiment was conducted to measure man's head aiming/tracking capability using a helmet mounted sighting device. The influences of target speed, helmet suspension types, and helmet weighting parameters on head aiming/tracking were investigated. If the aiming/tracking accuracy was sensitive to manipulation of these man-machine interface parameters, then it would seem to indicate that improved aiming/tracking accuracy could be obtained by improving the interface.

The factors analyzed were eye dominance, helmet weighting, target speed, and helmet suspension. The eye dominance, helmet weighting, and target speed factors were statistically significant; however, the only factor of practical significance was target speed. A subject aiming at a static target with his head had an RMS error of about 3 milliradians. Then the target began to move 4^0/second, the error increased to about 10.5 milliradians. When the subject began to vibrate too, the error increased to 13 milliradians. When the target speed doubled, the vibrating error increased to 16.8 milliradians.

Accession For	
NTIS GRA&I	☒
DDC TAB	☐
Unannounced	☐
Justification	
By	
Distribution/	
Availability Codes	
Dist	Avail and/or special
A	

SUMMARY

This experiment was conducted to measure man's head aiming/tracking capability using a helmet mounted sighting device. The influences of target speed, helmet suspension types, and helmet weighting parameters on head aiming/tracking were investigated. If the aiming/tracking accuracy was sensitive to manipulation of these man-machine interface parameters, then it would seem to indicate that improved aiming/tracking accuracy could be obtained by improving the interface.

The subject sat in a modeled AH-1 (Cobra) copilot's crewstation which was attached to the Multi-Axis Helicopter Vibration Simulator (MAHVS). The MAHVS vibration was programmed using an analog FM recording from x, y, z coaxial accelerometers mounted to the floor in the copilot's crewstation of an AH-1G. The Cobra flew the same mission profile the MAHVS was to simulate. A light in the center of a photocell array was used as a target for the subject to track. The 32x32 photocell array and target light moved in a quasi-random spherical path with constant velocity and a constant distance of 80 inches from the subject's eye position. The target traversed an area 110^{0} azimuth and 45^{0} in elevation. A beam of infrared light was projected from a small telescope mounted on the subject's helmet. This light beam was boresighted with the subject's reticle projector. As the subject tracked the target by superimposing his reticle on it, the coincident beam of infrared light would energize the appropriate photocell(s).

The output of the photocell board was sampled at 1,000 Hz and recorded digitally. Ten percent of the data was analyzed after each tracking period; this analysis was used to insure proper functioning of the electrical and mechanical systems.

The factors analyzed were eye dominance, helmet weighting, target speed, and helmet suspension. The eye dominance, helmet weighting, and target speed factors were statistically significant; however, the only factor of practical significance was target speed. A subject aiming at a static target with his head had an RMS error of about 3 milliradians. When the target began to move 4^{0}/second, the error increased to about 10.5 milliradians. When the subject began to vibrate too, the error increased to 13 milliradians. When the target speed doubled, the vibrating error increased to 16.8 milliradians.

ACKNOWLEDGMENTS

This experiment was possible because of the combined efforts of many laboratory personnel. More than a year was spent on design and fabrication; then followed many months of data collection. The specialized talents and dedicated efforts of the following people are gratefully acknowledged:

Test Director	CPT Robert W. Verona
Vibration System	CPT John C. Johnson Mr. Alan Lewis Mr. John Jenkins SP5 Carol Bucha
Computer System	Dr. Heber D. Jones Mr. Andy Higdon Ms. Sandy Sariego SP5 Carole Fleming
Electronic Systems	Mr. Charles Benefield Mr. Howard Beasley Mr. Robert Dillard
Mechanical Systems	Mr. Lynn Alford Mr. Paul Burns
Medical Monitors	CPT John Current CPT John Gearhart
Life Support Equipment	SSG Jerry Johnson Mr. Ted Hundley Mr. Joseph L. Haley
Subjects	MAJ Pierre Allemond MAJ Willis Haycock CPT Clarence Baker CPT Thomas Harrison CPT Raymond Mulcahy SSG Jerry Johnson
Vision Testing	Dr. Isaac Behar

ACKNOWLEDGMENTS (Cont)

Statistics	Mr. William Holt SP5 Hal Chaikin
Documentation	Mr. Jim Brooks Mr. John Sowell Mr. Jerry Jones SP5 Dave Taylor SP4 Jack Parker Ms. Jimmie Henderson Ms. Gail Jay Ms. Carolyn Johnson Ms. Sybil Bullock Ms. Linda Messer
Logistics	Mr. Charles D. Williams Ms. Charlotte B. Weeks SFC Earl T. Wright Ms. Joann Winston Ms. Josephine Muldoon

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

ILLUSTRATIONS (Cont)

ILLUSTRATIONS (Cont)

ILLUSTRATIONS (Cont)

ILLUSTRATIONS (Cont)

LIST OF TABLES

INTRODUCTION

Much interest has been generated in the aerospace community during recent years concerning Visually Coupled Systems (VCS). A VCS can be defined as a closed-loop technique utilizing the natural visual and motor skills of the operator to control a system function. The development of methods to accurately and remotely measure head position has enabled engineers to use the head as a control device. When the head tracker is used to orient an electro-optical (E-O) sensor whose video information is being viewed on a display also mounted on the head, a VCS is achieved.

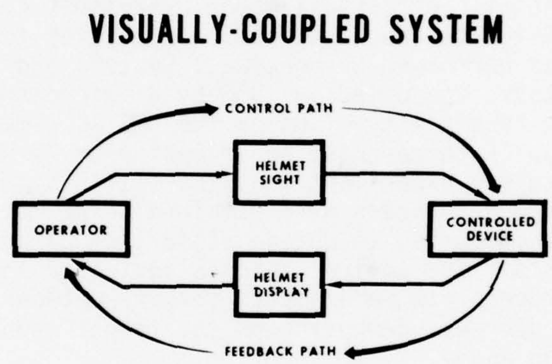


FIGURE 1. A Visual-Coupled System Block Diagram.

In airborne applications of VCS, some of the headtracker and display hardware must be mounted on the crewmember's helmet; thus, the terms "Helmet Mounted Display (HMD)" and "Helmet Mounted Sight (HMS)" are used to identify the display and tracker, respectively. Since the helmet alone introduces considerable weight to the operator's head, the additional weight contributed by the VCS hardware must be kept to an absolute minimum. This restriction is not only necessary so the aviator's safety is not compromised, but also so his performance is not encumbered.

PURPOSE

This experiment was conducted to measure man's head aiming/tracking capability using a helmet mounted sighting device. The influences of target speeds, helmet suspension types, and helmet weighting parameters on head aiming/tracking accuracy were investigated. If the aiming/tracking accuracy was sensitive to manipulation of these man-machine interface parameters, then it would seem to indicate that improved aiming/tracking accuracy could be obtained by improving the interface.

LITERATURE REVIEW

The only systematic perceptual-motor experiment conducted to measure the ability of the neck and shoulder muscles to effect head aiming/tracking was performed by Honeywell Systems and Research Division. This study, conducted in 1965 by R. Nicholson (1966), was to investigate the feasibility of using the HMS as a means of aiming an armament system. A three-phase experiment program was conducted. In Phase I a laboratory experiment measured static sighting accuracy. In Phase II tracking accuracies were obtained using moving targets. The last phase was conducted to obtain field test data for high speed, low altitude flights. The series of tests indicated that the accuracy of the sighting process can be expected to vary between a fraction of a degree and four degrees, depending on the target angular rate and the target sighting angle.

Other tests have been conducted to ascertain the performance characteristics of specific HMS systems under specific conditions (Haywood 1975, Polhemus 1976, Sawamura 1976). Bench tests were conducted at the Aerospace Medical Research Laboratory, Wright-Patterson Air Force Base (WPAFB), Ohio, using the Volna Test Station to obtain aiming performance data without the man in the system. Flight tests were conducted in high performance aircraft to obtain tracking/aiming performance data during tactical operating conditions (Grossman 1974).

An analysis of the previously referenced bench tests indicate that aiming accuracies are a function of the off-boresight angle and can be expected to vary from 0.01 degree for the forward quadrant to 1° for the rear quadrant (Polhemus 1975). An analysis of the flight test data indicates a median radial error of 0.8° and that 90% of the time the radial error was less than 2.2° over all off-boresight angles, g-loads and angular rates. However, rather than the performance of specific systems, the measures of interest in the present experiment were the limitations imposed by the man and man-machine interface.

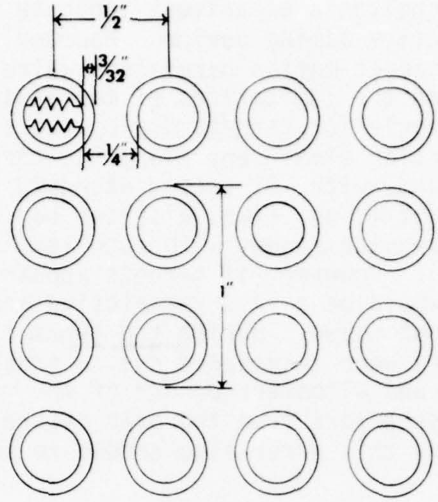
The results of Nicholson's experiment indicate that the head can be used as a very effective aiming device. However, Nicholson used a very limited range of target motion parameters which highlighted the capabilities rather than the limitations of the aiming functions. The maximum off-boresight angle for targets during the static aiming tests was only 10°. The reaction times vary among the three subjects, the average being 2.04 seconds with .81 second standard deviation. This indicates that, given sufficient time, a target can be held within a cross hair over small angular ranges with much less than 1° circular error probability (CEP). However, if targets appear greater than 10° from boresight, which would be a less restrictive and more realistic situation, the CEP is not known. During the dynamic portion of the testing, constant errors were introduced due to tracking/aiming bias errors of the observer and alignment errors of the measurement equipment. The author removed these errors from the data before analyzing it. The technique used to remove this error also tended to smooth the data.

METHODOLOGY

SIGHT SYSTEM

A thorough analysis of the empirical data obtained from flight tests and static bench tests of HMS devices indicated head aiming/tracking accuracies with a mean radial error of 13.6 milliradians (mr) had been obtained. In order to measure the man's capabilities alone, a device was designed which would measure static aiming accuracies to within 1.6 mr using a cooperative target. This device consists of a 32x32 photocell array (Figure 2). The photocells were positioned with their centers on 1/2 inch increments in X and Y.

Each photocell had two sensing elements, one activated the X axis and the other activated the Y axis (Figure 3). When a photocell was activated, it turned on CMOS switches--one for X position and the other for Y position. The switches activated voltage dividers and the position of the activated photocell was uniquely determined by the X, Y voltages. If two photocells were activated simultaneously, the arithmetic mean of the two cells was determined. This means the resolution of the array was 1/4 inch provided the activating source was approximately 3/4 inch in diameter. (The actual diameter was determined empirically.)



PHOTOCELL BOARD

FIGURE 2. Shown is a 4x4 photocell section of the entire 32x32 photocell board. The nominal 3/4 inch diameter beam of light could illuminate at most four photocells.

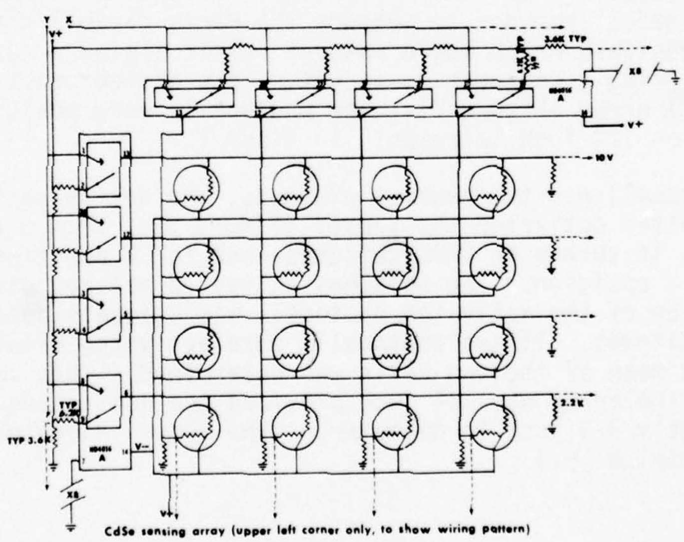


FIGURE 3. Schematic diagram of the photocell target showing photocells, CMOS switches, and voltage dividers for a 4x4 section of the entire 32x32 photocell array.

The activating source was a PBL 150 watt quartz iodide lamp with an IR 740 nm high pass filter (Figure 4). The energy from the lamp passed through a lightweight, noncoherent fiber-optic light guide to a telescope mounted on the subject's helmet. The emerging beam of infrared (IR) light was boresighted with the subject's reticle. The beam of light was 5/8 ± 1/8 inch in diameter as it impinged on the photocell array (Figure 5). The IR beam was not readily visible to the subject.

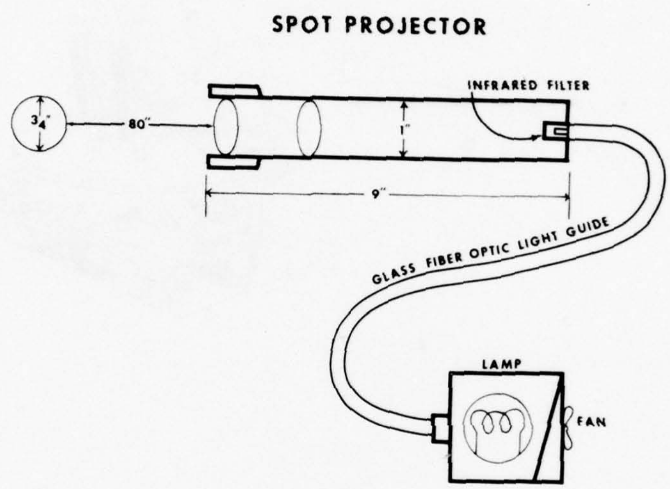


FIGURE 4. The lightweight spot projector shown was mounted to the subject's helmet. A 1/8 inch diameter, six foot long, very flexible glass fiber-optic light guide provided the light for the projector from a tungsten source located behind the subject's seat.

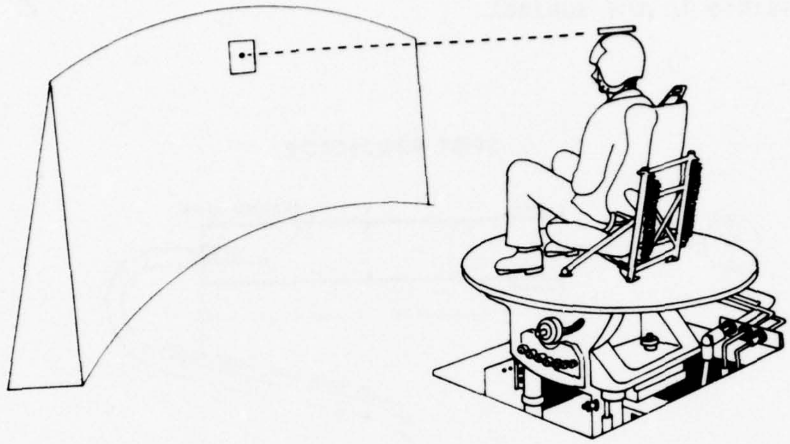


FIGURE 5. Sketch shows target board being illuminated by infrared spot projector mounted on subject's helmet.

Also mounted on the subject's helmet was a Sperry Rand sight reticle generator. This device generated an illuminated reticle of adjustable intensity; the collimated reticle could be viewed by either the right or left eye (Figure 6).

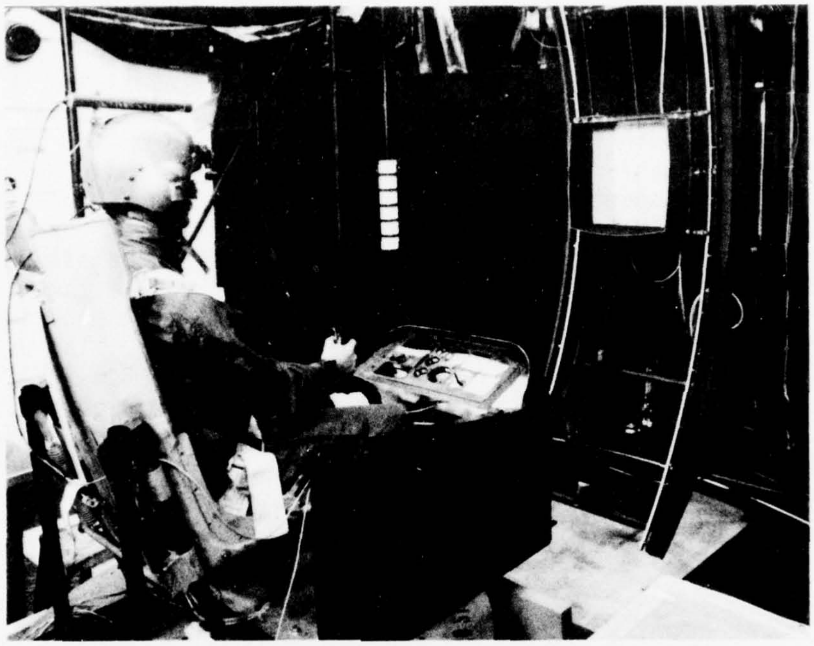


FIGURE 6. Subject is shown with reticle generator positioned in front of right eye and spot project mounted to subject's helmet. The target, photocell array, and moving target system (MTS) can be seen in the background.

Prior to starting each testing session, the subject's reticle and the spot of light from the helmet mounted projector were boresighted at 80 inches. As the subject aligned his reticle with the illuminated target, the experimentors adjusted the spot projector until it was centered on the illuminated target. The accuracy of the boresight was checked by observing the X, Y monitor and displayed voltage levels. Corrections to the mechanical adjustment were made electrically and statistically and will be described in more detail in the procedures section.

Target

A miniature lamp with a translucent white filter was installed in the center of the photocell array. This lamp was the target. The intensity of the lamp was controllable. The computer turned on the lamp to indicate the initiation of a tracking/aiming trial and turned off the lamp to indicate the conclusion of a trial. The photocell board with the lamp/target firmly affixed to its center was moved in a quasi-random direction at pre-determined constant velocities. The speeds of the target were 0°/second, 4°/second, and 8°/second. The target moved at a constant velocity throughout each 30-second tracking trial, but the direction and magnitudes of the acceleration vectors were constantly changing. The target transversed a spherical path $\pm 50^{\circ}$ in azimuth and $+30^{\circ}$ -15° elevation with a radius of 80 inches from the crewmember's design eye. The device that moved the array was called the moving target system (MTS). The Hybrid computer generated commands for the MTS servos to follow (Figure 7). The same quasi-random path was used for each subject since the same random numbers (therefore quasi-random) were generated each experimental session.

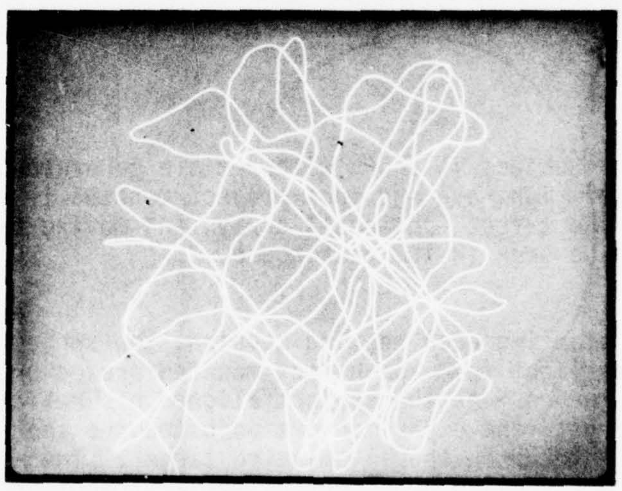


FIGURE 7. A typical series of target paths is shown on this storage display. Scaling factors were used to define target movement limits and rates.

Data Acquisition

The X and Y channels coming from the voltage dividers on the photocell array were observed on an X, Y monitor. These signals were simultaneously recorded for historical purposes on 14 channel FM instrumentation recorder and fed to the Hybrid computer.

Since the beam was constantly in motion, even when the target and the cockpit were in a static condition, some noise was introduced into the analog channels from the photocell array. To compensate for the noise generated in the photocell array and lines from the array to the analog portion of the Hybrid computer, a series of threshold levels were used by the computer to improve the signal to noise ratio. These threshold levels also compensated for nonlinearities in the voltage dividers. As a penalty, the static resolution of the photocell array was degraded, but the dynamic accuracy was not seriously affected. Thirty-two threshold levels were established in the X and Y channels (3.2 mr). The output of the photocell board was compared to the threshold levels and the result recorded at 1,000 Hz. A probability density histogram was generated from the 600 data points obtained in each axis during the 30-second tracking period. The statistics presented in this report were obtained from the analysis of these histograms.

The subject response switches, target servo position feedbacks, time code, intercom, target drive commands, and simulator accelerations were simultaneously displayed on oscilloscopes and recorded on the 14 channel recorder. The subject response switches, target servo position feedbacks, and time and time code were also sampled and recorded by the computer. At the conclusion of each 30-second tracking trial, the computer would analyze 10 percent of the tracking data and provide its analysis within seconds to the test director on a video display and hard copy. This procedure proved also to be an invaluable tool in troubleshooting the data acquisition hardware.

Vibration Environment

A 45-minute tactical scenario was flown in an attack helicopter (AH-1G) with three orthogonally mounted accelerometers secured to the copilot/gunner's floor panel. Simulated TOW and live 7.6 mm, 40 mm, and 2.75-inch rockets were fired. The accelerations measured at the copilot/gunner's floor panel were recorded as X, Y, and Z vibration components as indicated in Figure 8. The crew's communications were recorded also.

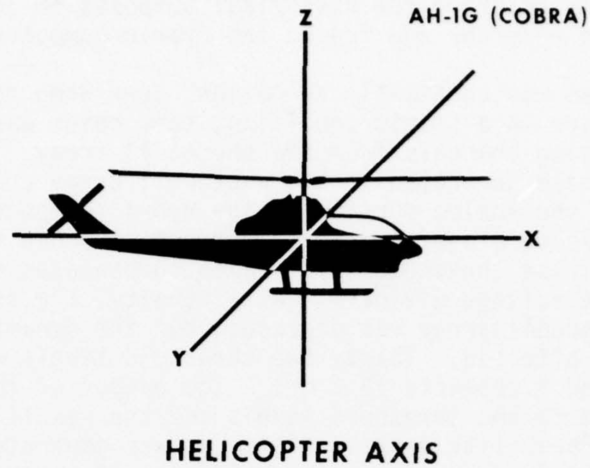


FIGURE 8. AH-1G (Cobra) showing coordinate axis orientations.

This 45-minute program was recorded twice on each of three 90-minute master tapes to be used throughout the test sequence. A time code was added to the tapes so the USAARL Hybrid computer could synchronize the aiming/tracking tasks with the vibration according to a predetermined schedule. Small sections of the vibration tapes were blanked since the accelerometers overload during gun firing. Master tape I was played for all data collection tests so that the Multi-Axis Helicopter Vibration System (MAHVS) replicated the helicopter vibrations experienced by the copilot/gunner during the actual flight and each subsequent simulator flight. Each tracking sequence and target movement was also repeated at the same time based on the time code information synchronized with the vibration signals.

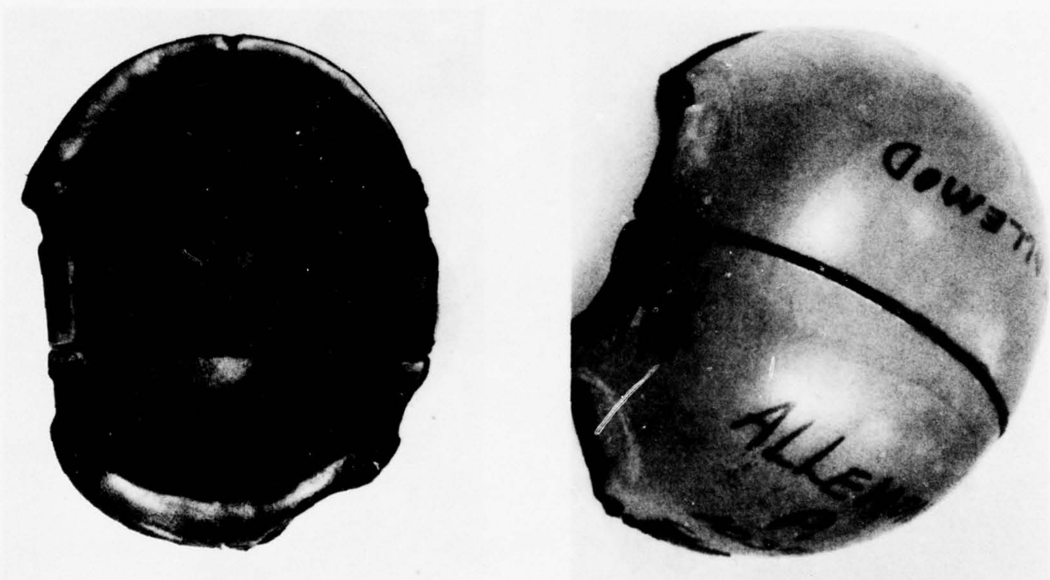
Subjects

Six Army aviators were used as subjects. Three were instructor pilots for the Cobra Transition Course at the US Army Aviation Center and two were US Army Aeromedical Research Laboratory pilots. The

sixth aviator had more than 1,000 hours of gunship experience in the Republic of Vietnam. All six subjects passed the standard static acuity and the dynamic acuity tests administered by an optometrist and research psychologist, respectively. The subjects were also given an eye dominance test described in Appendix A, Eye Dominance Test. One of the aviators wore glasses.

Helmets

The six aviator subjects were fitted for formfit helmets by Protection Incorporated personnel. Wax molds were made of the aviators' heads and plaster head forms were made from the molds. The foam liners for each SPH-4 lightweight helmet were then fitted to a particular individual's head form. The hard foam liners were covered with soft foam and leather and the backs were reinforced with fiberglass. The fiberglass reinforcement enabled the helmet technician to remove and insert the foam liners in the test helmet without damage to the delicate foam inserts (Figure 9). Absorbent cotton skull caps were worn by the subjects to reduce possible heat discomfort.



(A) Inside

(B) Outside

FIGURE 9. Formfit inserts used to customize the experimental helmet to a specific subject's head shape: (A) Inside; (B) Outside.

The weight and center of gravity (cg) of the test helmet were adjusted to conform to the weight and center of gravity of the standard issue SPH-4 during the symmetrically weighted condition and to the projected integrated helmet display/sight system (IHADSS) weight and cg with the display during the asymmetrically weighted condition (Figure 10). See Appendix B, Helmet Center of Gravity (CG) Determination, for weight/cg details.

FIGURE 10. Test helmet shown without custom foam inserts. Lead weights were used to achieve the desired weight and cg characteristics.

Cockpit

A metal mock-up of an AH-1G copilot/gunner crewstation less canopy was fabricated and installed on the MAHVS (Figure 11).

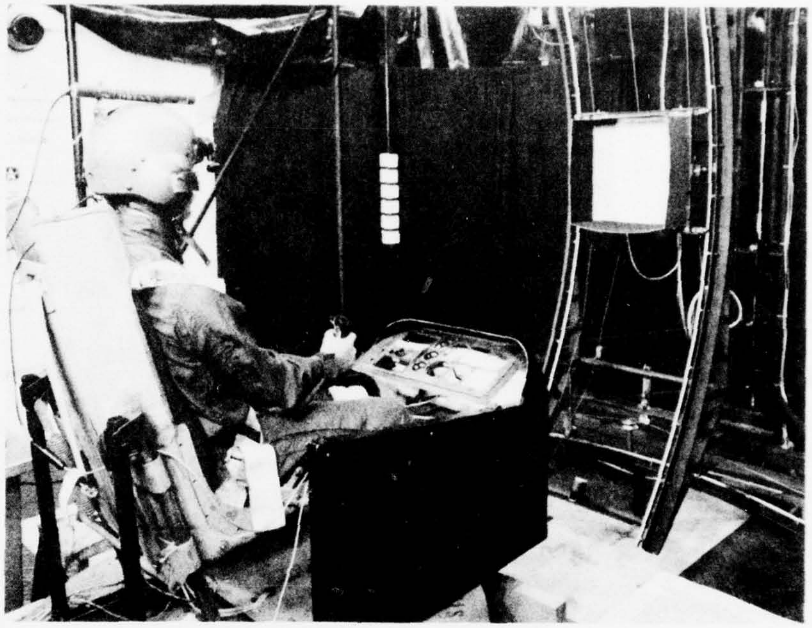


FIGURE 11. A metal mock-up of an AH-1G cockpit secured to the Multi-Axis Helicopter Vibration Simulator.

The crewstation geometry, seat, instrument panel, and pedals were authentic. The cyclic control, however, was mounted on the floor, as in the pilot's crewstation, instead of its normal location. The trigger switch on the cyclic was used by the pilot to indicate when he began to track the target and his tracking confidence. The pilots were directed to squeeze the trigger switch on the cyclic to the first detent as soon as they saw the target illuminate. The computer began taking and scoring data at this time. The subjects were directed also to squeeze the trigger to the second detent as long as they had enough confidence to "fire" a point-fire weapon at the target. The computer

graded this data as "high confidence" data. The information contained in this report is based on the sum of all the data without regard to tracking confidence.

Procedures

Testing sessions were conducted 4 days a week from 1300 hours to 1530 hours; no sessions were conducted on Friday. Subjects were scheduled at least 1 week in advance with no less than 1 day between successive sessions. Equipment maintenance, check-out, and calibration were conducted each morning.

The test helmet was configured and fit for the condition to be tested during the day's session. USAARL's life support equipment specialist personally fit and checked each subject before and after each session. The subject also signed the consent forms and had his neck measured and marked prior to entering the simulator.

The timekeeper insured all systems were operational and in the proper status before the subject mounted the crewstation. After all stations reported, the subject was assisted into the crewstation, the room lights were extinguished, and the subject's reticle and spot projector were boresighted with the help of the controller and test director. The timekeeper then reviewed the subject's control functions and instruction. The controller, when directed by the timekeeper, would move the target/photocell array to the upper right corner of the MTS (45° AZ, 50° EL) and activate the target light. Also, at the command of the timekeeper (Figure 12), the subject would

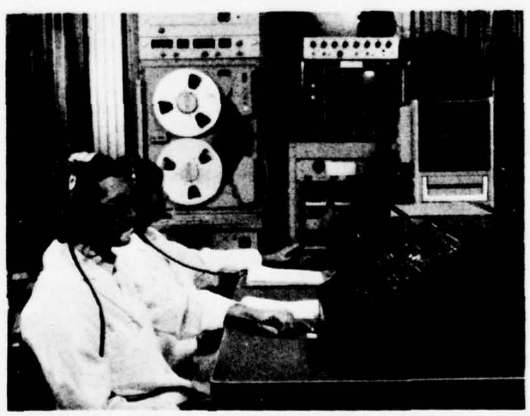


FIGURE 12. Controller and timekeeper, shown near and far respectively, prepare to begin experiment. Tape recorders and X, Y monitor are shown in background.

aim at the target and squeeze the trigger on the collective, and the computer terminal operator (Figure 13) would initiate data collection.

FIGURE 13. Terminal operator initializes computer program, monitors computer operations, notifies test personnel of error messages, and insures completeness of "quick-look" data at the end of each data trial. Hard copy of data is generated at this position also.

When the 30 seconds of data were collected, the computer would extinguish the target light and the subject would relax. In the same manner, data were collected from the center (0° AZ, 0° EL) position and lower left (-30° AZ, -50° EL) position. The controller watched the X, Y monitor and oscilloscopes to insure system operation, and the test director reviewed the computer data summary for each trial.

At the conclusion of the static tests, the dynamic tests began. The timekeeper would check with the MAHVS operator to insure all MAHVS systems were operational and the medical monitor was on call (Figure 14). When affirmed, the timekeeper would initiate the program tape and

FIGURE 14. The Multi-Axis Helicopter Vibration Simulator (MAHVS) operator monitors system performance. In the event of a system malfunction, the operator must disarm hydraulic systems, correct deficiency, and reinitialize simulator. Controller, timekeeper, and subject stations shown in background.

time-code decoder. When the time-code on the tape began counting, the computer terminal operator was directed to synchronize the computer to the program tape. Within seconds the experiment would begin. The MAHVS operator was then directed by the timekeeper to put the MAHVS in computer operator mode. The controller was likewise directed to put the MTS in computer operator mode (Figure 15).

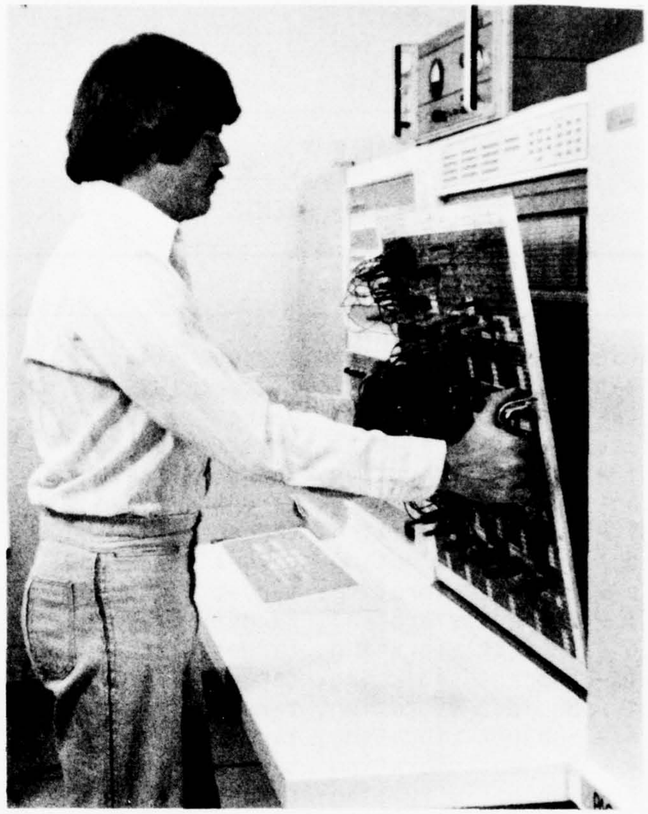


FIGURE 15. Computer programmer inserts program board into PACER 600 Analog Computer. The Analog Computer, under control of the SEL 8500 Digital Computer, controls moving target system (MTS), data acquisition, Multi-Axis Helicopter Vibration System (MAHVS), and monitors all control functions and indicators.

Ten seconds prior to each tracking sequence, the timekeeper would notify the subject that a sequence was about to begin. The first and twenty-first track occurred when the MAHVS was static. These are called test tracks; the target moved at 4^0/second but the MAHVS was static. The tracking events schedule is shown in Table 1. At the conclusion of the dynamic tracking test, the static tests were repeated.

TABLE 1

TABLE OF EVENTS

EVENT	DESCRIPTION
1	Static - Subject static, target (+45, -50)
2	Static - Subject static, target (0, 0)
3	Static - Subject static, target (-30, +50)
4	Test - Subject static, target 4^0/second
5	Hi - Subject vibrating, target 8^0/second
6	Lo - Subject vibrating, target 4^0/second
7	Hi - Subject vibrating, target 8^0/second
8	Lo - Subject vibrating, target 4^0/second
9	Lo - Subject vibrating, target 4^0/second
10	Hi - Subject vibrating, target 8^0/second
11	Lo - Subject vibrating, target 4^0/second
12	Hi - Subject vibrating, target 8^0/second
13	Hi - Subject vibrating, target 8^0/second
14	Lo - Subject vibrating, target 4^0/second
15	Hi - Subject vibrating, target 8^0/second
16	Hi - Subject vibrating, target 8^0/second
17	Lo - Subject vibrating, target 4^0/second
18	Hi - Subject vibrating, target 8^0/second
19	Hi - Subject vibrating, target 8^0/second
20	Hi - Subject vibrating, target 8^0/second
21	Lo - Subject vibrating, target 4^0/second
22	Lo - Subject vibrating, target 4^0/second
23	Lo - Subject vibrating, target 4^0/second
24	Lo - Subject vibrating, target 4^0/second
25	Test - Subject static, target 4^0/second
26	Static - Subject static, target (45, 50)
27	Static - Subject static, target (0, 0)
28	Static - Subject static, target (-30, -50)

Use of clever computer programming techniques enabled this experiment to be conducted without disrupting normal data crunching operations. The computer had a disk file with the schedule of tracking event and an associated time for each event. It would monitor the time code being read from the analog vibration master tape discussed earlier. Thirty seconds before a data trial was to begin, the program would start easing other uses out of the central processing unit (CPU). Any hard liners would be aborted 10 seconds before the data trial was to begin. The monitor would then load the larger program. After the 30 seconds of data was collected and partially analyzed, the program would determine how long before another data trial. If the time exceeded 1 minute, the large program would exit, leaving the monitor to determine when to reload again (Figure 16).

When the tests were completed, the subject was debriefed by the test director and his neck was again measured. The neck measurement, vibration time, and debriefing information were logged.

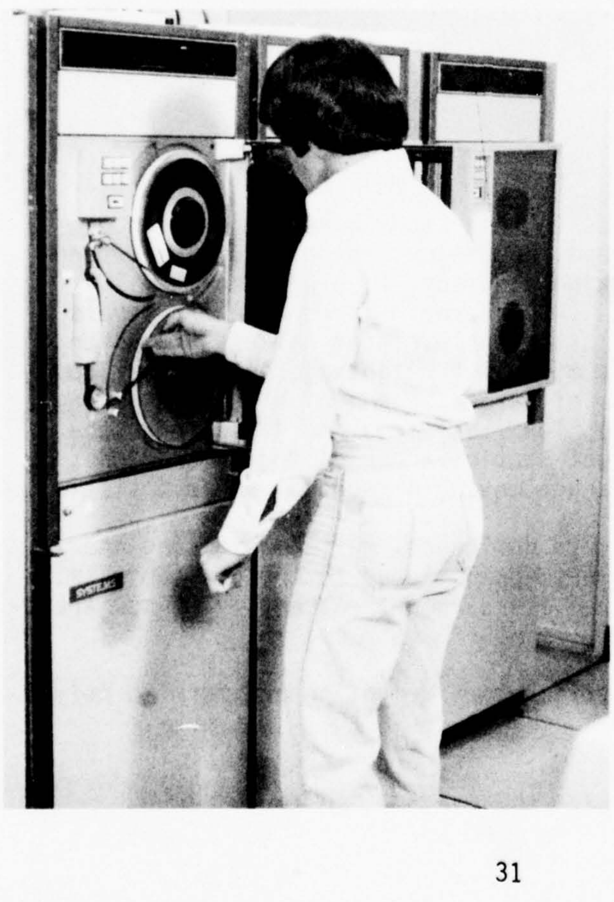


FIGURE 16. Computer programmer mounts tape to collect digitized aiming/tracking data generated during experiment.

Safety

A multitude of precautions were taken to insure the subject's safety during the experiment. The MAHVS is equipped with a sophisticated fail-safe system that shuts down the hydraulic systems at the slightest irregularity. The subject held a fail-safe switch closed during the periods the MAHVS was operating. If the subject released the switch, the system would immediately shut down.

The inter-communications systems provided the subject with a "hot mike" so that all personnel in the area could monitor him. A closed circuit, low light level television camera was trained on the subject so that his actions could be viewed by the MAHVS operator and recorded. These tapes were retained for historical documentation.

A sophisticated radio communications system was also installed so the MAHVS operator could notify an on-call flight surgeon and the hospital emergency room if an accident occurred.

RESULTS

DATA

The independent variables in this study were eye dominance, helmet suspension, target speed, and helmet weighting. The dependent variable was aiming/tracking accuracy, E, expressed in milliradian (mr) root mean squared (RMS) error. There were two levels of eye dominance, right and left; two levels of helmet suspension, formfit and sling; two levels of helmet weighting, symmetrical and asymmetrical; and four levels of target speed: high (target moving 8^0/second; subject vibrating), low (target moving 4^0/second; subject vibrating), static (target static in one of three locations; subject static), and test (target moving 4^0/second; subject static).

Six combinations of the eye dominance, helmet weighting and helmet suspension variables were administered to the six subjects; each combination was considered a separate treatment. The six treatments were:

A. Dominant eye, symmetric helmet weighting and formfit helmet suspension.

B. Dominant eye, asymmetric helmet weighting and sling helmet suspension.

C. Non-dominant eye, symmetric helmet weighting and formfit helmet suspension.

D. Non-dominant eye, asymmetric helmet weighting and formfit helmet suspension.

E. Dominant eye, symmetric helmet weighting and sling helmet suspension.

F. Dominant eye, asymmetric helmet weighting and formfit helmet suspension.

The treatments were administered in the order indicated in Table 2. The combination of non-dominant eye viewing and sling helmet suspension was not administered to the subjects during the study. This limitation was imposed because of schedule constraints for the MAHVS; adding this condition would have extended the data collection sessions two more weeks.

TABLE 2

EXPERIMENTAL DESIGN*

	DOMINANT EYE				NON-DOMINANT EYE	
	FORMFIT		SLING		FORMFIT	
TREATMENT	SYM (A)	ASY (F)	SYM (E)	ASY (B)	SYM (C)	ASY (D)
S_1	1	6	3	4	5	2
S_2	2	5	6	1	3	4
S_3	3	4	2	5	1	6
S_4	4	3	5	2	6	1
S_5	5	2	1	6	4	3
S_6	6	1	4	3	2	5

*Four target speeds for each treatment not shown.

The 6x6 Latin Square order of presentation was used to minimize the learning effects.

The aiming/tracking data collected during this study are analyzed as though two separate experiments had been conducted. In Case I, eye dominance data are analyzed in addition to helmet weighting, target speed, and subject variables. The formfit suspension is a constant factor for the Case I analysis. The data for the Case I analysis are obtained from treatments A, C, D, and F. The raw data for Case I analysis are shown in Table 3.

In Case II, helmet suspension data are analyzed in addition to helmet weighting, target speed, and subject variables. The dominant eye is a constant factor for the Case II analysis. The data for Case II analysis are obtained from treatments A, B, E, and F. The raw data for Case II analysis are shown in Table 4.

The figures in Tables 3 and 4 were calculated from the line-of-sight (LOS) data obtained from photocell board X and Y output voltages; the position of the light beam on the photocell board produced the output voltages. These outputs were sampled and recorded each millisecond during the 30-second aiming/tracking trial. The mean and standard deviation of the 30,000 and 30,000 photocell coordinates were calculated using the following equations:

$$(1) \quad \overline{X} = \sum_{i=1}^{30,000} \frac{Xi}{30,000}$$

$$(2) \quad \overline{Y} = \sum_{i=1}^{30,000} \frac{Yi}{30,000}$$

$$(3) \quad \alpha_x^2 = \sum_{i=1}^{30,000} \frac{(Xi - \overline{X})}{30,000}$$

$$(4) \quad \alpha_y^2 = \sum_{i=1}^{30,000} \frac{(Yi - \overline{Y})}{30,000}$$

TABLE 3

RAW AIMING/TRACKING DATA - CASE I

SUB-JECT		STATIC				TEST				LOW				HIGH			
		DOM		NON DOM		DOM		NON DOM		DOM		NON DOM		DOM		NON DOM	
		SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY
1.	M	2.40	2.49	4.499	2.35	11.14	9.56	15.90	13.03	14.50	12.44	17.37	14.66	17.54	17.88	22.71	17.77
	SD	0.97	0.53	2.472	1.26	0.05	2.80	4.61	6.67	2.94	1.79	3.41	3.48	1.54	1.89	4.23	1.89
2.	M	3.25	3.55	2.33	3.46	8.63	12.45	8.63	9.71	11.56	11.47	11.24	11.01	15.08	13.63	14.29	13.37
	SD	0.53	0.43	0.94	0.87	0.08	1.54	0.13	3.48	1.00	1.81	1.26	0.95	1.25	1.13	1.48	1.17
3.	M	2.56	2.47	3.16	4.35	8.51	9.10	11.09	10.37	10.82	11.57	11.68	12.20	13.82	14.61	14.66	15.40
	SD	0.66	1.10	0.71	2.48	1.09	1.86	0.90	0.51	0.93	1.11	1.76	1.18	1.77	1.25	1.35	1.67
4.	M	1.34	2.73	2.62	2.38	7.98	9.89	8.11	7.86	11.36	11.60	11.52	11.45	13.30	16.73	14.42	12.93
	SD	1.03	0.92	0.49	0.70	0.60	0.15	1.06	0.28	1.33	1.88	1.07	0.97	1.29	1.30	1.57	0.70
5.	M	2.108	3.84	3.27	3.39	12.84	10.44	12.82	13.61	15.97	12.63	13.60	15.42	18.96	15.93	17.22	20.37
	SD	1.580	0.65	0.80	1.49	5.79	3.19	0.30	1.00	3.32	1.60	0.97	2.19	1.92	1.48	1.82	2.19
6.	M	3.16	3.65	3.29	3.95	13.08	12.57	8.22	14.42	15.34	13.97	15.32	17.45	18.00	16.52	16.52	20.27
	SD	0.80	0.647	1.51	1.08	2.66	0.91	4.38	2.13	1.89	1.92	1.05	2.12	1.04	1.76	1.38	1.81

TABLE 4

RAW AIMING/TRACKING DATA - CASE II

SUB-JECT		STATIC				TEST				LOW				HIGH			
		FORM FIT		SLING		FORM FIT		SLING		FORM FIT		SLING		FORM FIT		SLING	
		SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY	SYM	ASY
1.	M	2.40	2.49	1.68	2.92	11.14	9.56	13.06	11.48	14.50	12.44	13.01	16.37	17.54	17.88	18.13	19.74
	SD	0.97	0.53	0.53	0.52	0.05	2.80	3.25	3.34	2.94	1.79	1.35	2.87	1.54	1.89	1.59	1.73
2.	M	3.25	3.55	2.45	2.51	8.63	12.45	7.90	10.18	11.56	11.47	11.14	11.01	15.08	13.63	13.30	16.00
	SD	0.53	0.43	0.63	1.09	0.08	1.54	0.81	1.05	1.00	1.81	0.82	1.69	1.25	1.13	1.06	1.20
3.	M	2.56	2.47	2.43	3.20	8.51	9.10	9.38	8.66	10.82	11.57	11.29	10.87	13.82	14.61	15.51	13.88
	SD	0.66	1.10	1.33	0.71	1.09	1.86	2.64	0.78	0.93	1.11	0.78	1.24	1.77	1.25	1.48	1.63
4.	M	1.34	2.73	2.62	2.18	7.98	9.89	7.45	7.34	11.36	11.60	11.55	11.20	13.30	16.73	13.47	14.20
	SD	1.03	0.92	0.67	1.32	0.60	0.15	0.22	0.63	1.33	1.88	1.03	1.19	1.29	1.30	1.31	1.55
5.	M	2.108	3.84	2.24	2.30	12.84	10.44	13.31	10.41	15.97	12.63	13.45	13.14	18.96	15.93	16.87	16.90
	SD	1.580	0.65	0.49	1.35	5.79	3.19	1.17	0.26	3.32	1.60	1.33	1.18	1.92	1.48	1.28	2.29
6.	M	3.16	3.65	3.09	3.39	13.08	12.57	9.60	12.23	14.14	15.34	14.13	13.72	17.45	18.00	16.99	17.51
	SD	0.80	0.64	1.18	0.62	2.66	0.91	1.10	1.75	1.89	1.92	1.20	1.65	1.04	1.76	2.02	1.35

The standard deviation of the photocell coordinates were then converted to subtended visual angles using the following equation:

$$(5) \quad \mathrm{Tan}^{-1} \frac{s}{d} = \theta$$

For: d = 80 inches subject to target distance
s = 0.5 inches distance between photocell centers
$\theta = 0.358^{0} = 6.088$mr

The x and y standard deviations were then converted into radial values. The photocell coordinates were transformed into subtended visual angles by multiplying the photocell coordinates by 6.088 mr/photocell. Since the $\overline{X}$ and $\overline{Y}$ were approximately equal to zero:

$$(6) \quad r^2 = \alpha_r^2 = (\overline{X}-\alpha_X)^2 + (\overline{Y}+\alpha y)^2 = (\alpha^2 + \alpha^2 y)$$

The α_r values were then averaged over the number of replicates on the same condition; the mean and standard deviations of α_r are listed in Tables 3 and 4. The resulting values of α_r are somewhat inflated by using the equations and techniques discussed above. The X and Y values are treated independently rather than as paired values, i.e., X_1, Y_1. For comparison purposes, however, the data techniques used are considered acceptable.

STATISTICS

Two statistical analysis techniques were applied to both Case I and Case II data. The first analysis was a 2x2x4 factorial analysis with repeated measures. The second analysis, a 2x2x4x6 factorial analysis with repeated measures, used subjects as a factor. In Case I and Case II the factors were completely crossed and the treatments were counterbalanced. Analysis of Variance (ANOVA) computer programs and manual techniques were used to analyze the data. The two computer statistical analysis packages used were "Revised MANOVA Program" by Elliot Cramer (1974) and "Biomedical Statistical Programs" from the University of California, Los Angeles (Dixon 1973). The same results were obtained from each method of analysis.

Case I Analysis

The ANOVA was applied to the Case I data using aiming/tracking accuracy as the criteria measure (univariate). The factors tested were eye dominance, helmet weighting and target speed. Each subject received all treatments. The ANOVA Summary Table is shown in Table 5. The p values less than 0.1 are considered statistically significant ($p < 0.1$).

TABLE 5

ANALYSIS OF VARIANCE CASE I

SOURCE OF VARIATION	SS	df	MS	F	p
Eye Dominance	45.722	1	45.722	6.859	0.009
Helmet Weight	0.908	1	0.908	0.136	0.712
Target Speed	16299.598	3	5433.199	815.090	0.001
Eye Dominance X Helmet Weight	0.947	1	0.947	0.142	0.706
Eye Dominance X Target Speed	0.837	3	0.279	0.042	0.989
Helmet Weight X Target Speed	11.656	3	3.885	0.583	0.626
Eye Dominance X Helmet Weight X Target Speed	7.897	3	2.632	0.395	0.757
Within Cells	4352.746	653	6.666		

The eye dominance factor is statistically significant ($p < 0.009$), but the helmet weighting factor is not statistically significant ($p < 0.7$). The target speed factor has overwhelming statistical significance ($p < 0.001$). None of the interactions are statistically

significant. Since the majority of the data variability is accounted for in a consistent manner by the target speed factor, the F values for the interactions are less than one.

The second analysis uses subjects as a factor; the analysis becomes more complex. The ANOVA Summary Table, Table 6, shows eye dominance statistically significant ($p < 0.001$). Target speed and subject factors are also statistically significant ($p < 0.001$). The helmet weighting factor is not statistically significant ($p < 0.59$), but unlike the previous analysis, the interactions are statistically significant. The target speed x subject, eye dominance x subject, and helmet weight x subject interactions are statistically significant ($p < 0.001$). The only three-way interaction statistically significant is eye dominance x helmet weighting x subject ($p < 0.001$) as is the four-way interaction, eye dominance x helmet weighting x target speed x subject ($p < 0.001$). Again, most of the variability is accounted for in a consistent manner by the target speed factor. The subject factor in this analysis also accounts for much of the variability but in a less consistent manner, thus the significant interactions.

Case II Analysis

The ANOVA was applied to the Case II data using aiming/tracking accuracy as the criteria measure (univariate). The factors tested were helmet suspension, helmet weighting, and target speed. Each subject received all treatments. The ANOVA Summary Table is shown in Table 7. The p values less than 0.1 are considered statistically significant.

The helmet suspension factor is not statistically significant ($p < 0.32$), and neither is the helmet weighting factor ($p < 0.224$). The target speed factor is statistically significant ($p < 0.001$); it has overwhelming significance. None of the interactions are statistically significant. As in Case I, the majority of the data variability is accounted for in a consistent manner by the target speed factor; therefore, F value for the Case II interactions is less than one.

TABLE 6

ANALYSIS OF VARIANCE CASE I

(Subjects As A Factor)

SOURCE OF VARIATION	SS	df	MS	F	p Less Than
Eye Dominance	45.721	1	45.721	14.730	.001
Helmet Weighting	0.908	1	0.908	0.293	.589
Target Speed	16299.566	3	5433.187	1750.372	.001
Subjects	1384.195	5	276.839	89.187	.001
Eye Dominance x Helmet Weight	0.995	1	0.995	0.321	.572
Eye Dominance x Target Speed	0.635	3	0.212	0.068	.977
Eye Dominance x Subjects	153.281	5	30.656	9.876	.001
Helmet Weight x Target Speed	10.163	3	3.388	1.091	.352
Helmet Weight x Subject	204.323	5	30.656	9.876	.001
Target Speed x Subject	356.701	15	23.780	7.661	.001
Eye Dominance x Helmet Weight x Target Speed	9.123	3	3.041	0.980	.402
Eye Dominance x Target Speed x Subject	54.852	15	3.657	1.178	.284
Eye Dominance x Helmet Weight x Subject	219.673	5	43.935	14.154	.001
Helmet Weight x Target Speed x Subject	56.675	15	3.778	1.217	.253
Eye Dominance x Helmet Weight x Target Speed x Subject	144.848	15	9.657	3.111	.001
Within Cells	1778.603	513	3.104		

TABLE 7

ANALYSIS OF VARIANCE CASE II

SOURCE OF VARIATION	SS	df	MS	F	p
Suspension	4.587	1	4.587	0.986	.321
Helmet Weighting	6.903	1	6.903	1.483	.224
Target Speed	116475.348	3	5491.781	1179.940	0.001
Suspension X Helmet Weight	6.881	1	6.881	1.478	.224
Suspension X Target Speed	2.082	3	0.694	0.149	0.930
Helmet Weight X Target Speed	11.574	3	3.858	.829	0.478
Suspension X Helmet Weight X Target Speed	9.574	3	3.191	0.686	0.561
Within Cells	3048.560	655	4.654		

The second analysis uses subjects as a factor; the analysis becomes more complex. The ANOVA Summary Table, Table 8, shows the helmet suspension factor not to be statistically significant ($p < 0.156$). Helmet weighting, however, becomes statistically significant ($p < 0.09$). The target speed and subject factors are also statistically significant ($p < 0.001$). The suspension x helmet weighting interaction is also significant ($p < 0.084$). The three-way interactions, helmet suspension x helmet weighting x subjects and helmet weighting x target speeds x subjects, are statistically significant ($p < 0.001$ and $p < 0.005$, respectively).

The other three-way interactions are not statistically significant, but the four-way interaction, helmet suspension x helmet weighting x target speed x subject, is statistically significant ($p < 0.001$). Again, the majority of the variation is accounted for by the target speed factor. The subject factor also accounts for much of the variation but in a less consistent manner, thus the statistically significant interactions.

TABLE 8

ANALYSIS OF VARIANCE CASE II

(Subjects As A Factor)

SOURCE OF VARIATION	SS	df	MS	F	p
Suspension	4.737	1	4.737	2.022	0.156
Helmet Weighting	6.903	1	6.903	2.947	0.087
Target Speed	16745.352	3	5491.785	2344.8	0.001
Subjects	957.728	5	191.546	81.783	0.001
Suspension x Helmet Weight	7.022	1	7.022	2.998	0.084
Suspension x Target Speed	2.079	3	0.693	0.296	0.828
Suspension x Subjects	58.969	5	11.794	5.036	0.001
Helmet Weight x Target Speed	11.324	3	3.775	1.612	0.186
Helmet Weight x Subjects	78.195	5	15.639	6.677	0.001
Target Speed x Subjects	273.445	15	18.230	7.783	0.001
Suspension x Helmet Weight x Target Speed	9.562	3	3.187	1.361	0.254
Suspension x Helmet Weight x Subject	108.095	5	21.619	9.231	0.001
Suspension x Target Speed x Subject	39.809	15	2.654	1.133	0.323
Helmet Weight x Target Speed x Subject	78.035	15	5.202	2.221	0.005
Suspension x Helmet Weight x Target Speed x Subject	107.547	15	7.170	3.061	0.001
Within Cells	1346.714	575	2.342		

DISCUSSION

This experiment required great manpower and hardware resources. Many answers had to be provided in a relatively short period of time. In order to minimize the resource drain and provide answers in a timely manner, the non-standard experimental design was required. The separation of the data for the analysis by Case I and Case II, although not efficient from some viewpoints, proved to be the most viable method of analyzing the data. A complete design would have required significantly more resources and the advantages would have been purely academic. The sequence effects were minimized by using the 6x6 Latin Square order of presentation. The inherent counter-balancing in this design tended to prevent sequence effects from being completely confounded with treatment effects. The sequence effects are instead spread over the treatments. Admittedly, such sequence effects tend to mask treatment effects, but the advantages in this study greatly outweighed the disadvantages.

This experiment was conducted to provide information so that hardware decisions could be made based on objective data rather than speculation. With this thought in mind, this discussion section will emphasize the practical significance as well as the purer statistical significance of the experimental results.

CASE I

The aiming/tracking performance of the subjects, although statistically better with the dominant eye, is only improved on the average 6.1% (Figure 17).

The mean performances using the symmetrically and the asymmetrically weighted helmets were essentially the same (Figure 18); no statistically significant difference was observed.

The performance changes with target speed levels are much more profound (Figure 19).

When the target was static and the subject was static, the average accuracy was 3.5 mr. As the target began to move at 4^0/second, the mean accuracy degraded to 11 mr. When the subject began to experience vibration too, the mean accuracy degraded to 13.3 mr. An increase of target speed to 8^0/second caused the accuracy to further degrade to

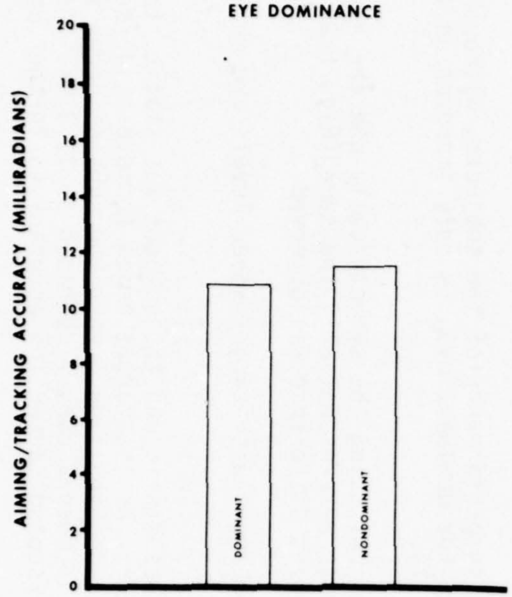


FIGURE 17. Eye Dominance

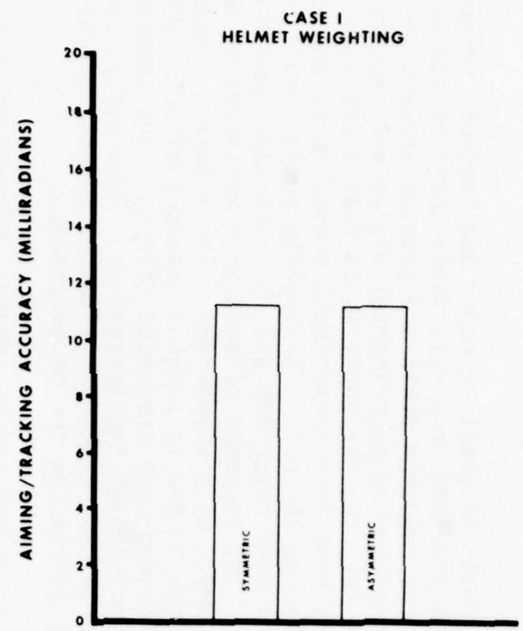


FIGURE 18. Case I, Helmet Weighting

16.3 mr. The percentage changes were 217%, 283%, and 366%, respectively, from the static case. The target speed factor accounted for such an overwhelming portion of the variation that the factor interaction involving target speeds have F ratios less than one.

The target speed x eye dominance data (Figure 20) show the dominant eye performance is better than the non-dominant eye performance at all target speed conditions. The improvement seems to be absolute rather than a constant percentage across all target speed conditions.

The target speed x helmet weighting data (Figure 21) show less consistency.

The subjects performed better with the asymmetric helmet weighting in the static and low speed conditions, better with the symmetric helmet weighting in the test condition, and about the same in high speed condition.

The helmet weighting x eye dominance data (Figure 22) show performance differences of about 10% from the best to worst case, dominant asymmetric to non-dominant asymmetric, respectively. It is surprising to see the asymmetric weighting performance is better for the dominant eye condition.

The three-way interaction of target speed x eye dominance x helmet weighting is not statistically significant ($p < 0.76$); the data (Figure 23) once again show the target speed variability overshadowing other differences. The eye dominance differences are somewhat less obvious but, nevertheless, seem to exist.

The analysis using subjects as a factor will now be discussed. The rationale for including subjects as a factor is--if individual differences are a source of great variation, this is an important factor to be investigated by itself and in its interactions with the other factors. If some subjects perform better with one combination of factors and another performs better with another combination, valuable information is obtained for the hardware developers that should not be discarded.

Figure 24 shows the subjects do perform differently ($p < 0.001$), as one might expect. The range is from 9.1 mr to 12.5 mr, a 37% difference from best to worst on the average.

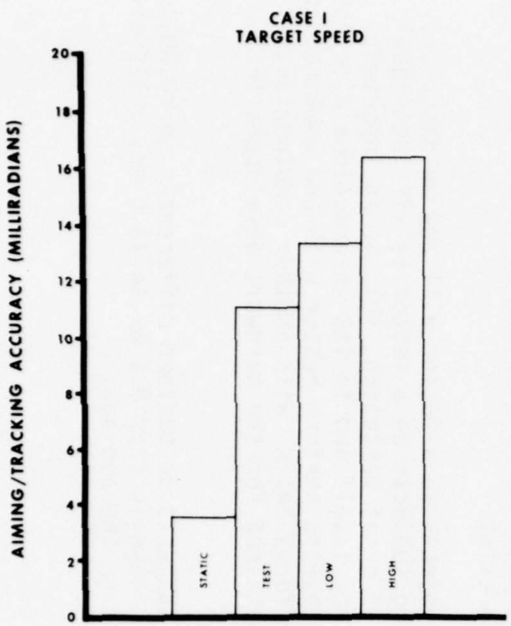


FIGURE 19. Case I, Target Speed

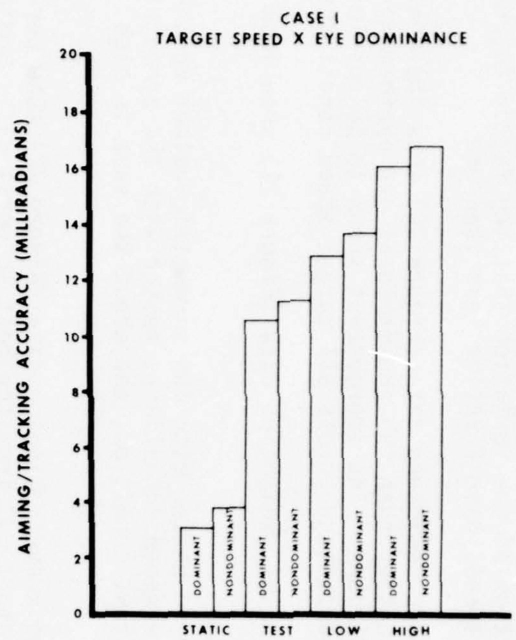


FIGURE 20. Case I, Target Speed X Eye Dominance

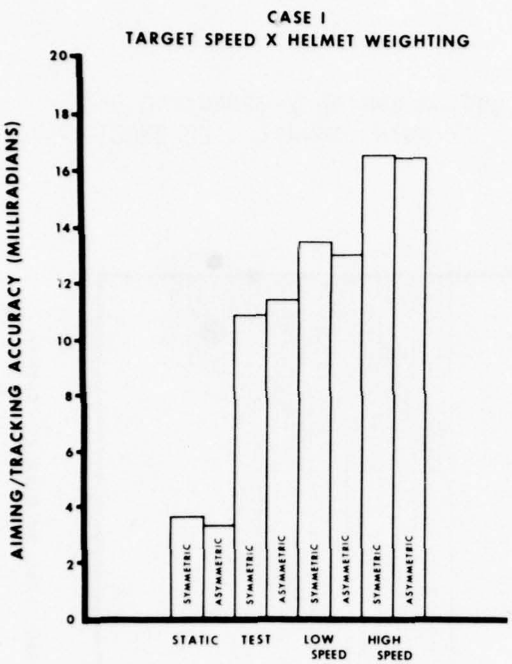


FIGURE 21. Case I, Target Speed X Helmet Weighting

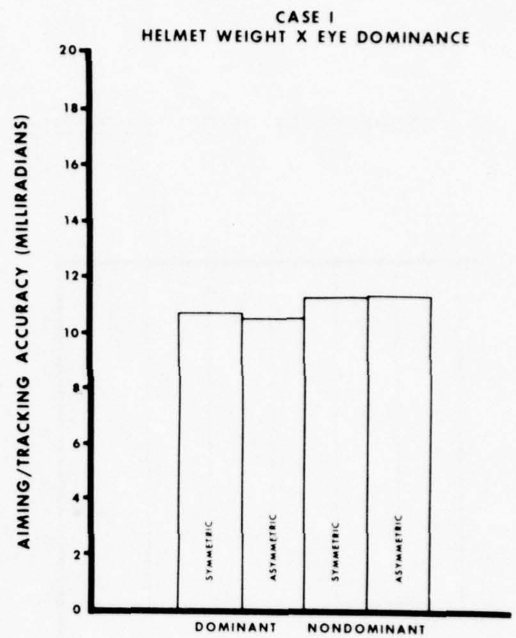


FIGURE 22. Case I, Helmet Weight X Eye Dominance

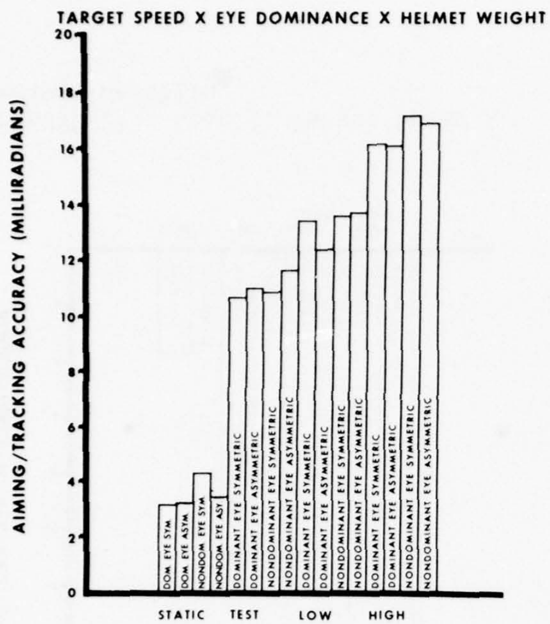


FIGURE 23. Target Speed X Eye Dominance X Helmet Weight

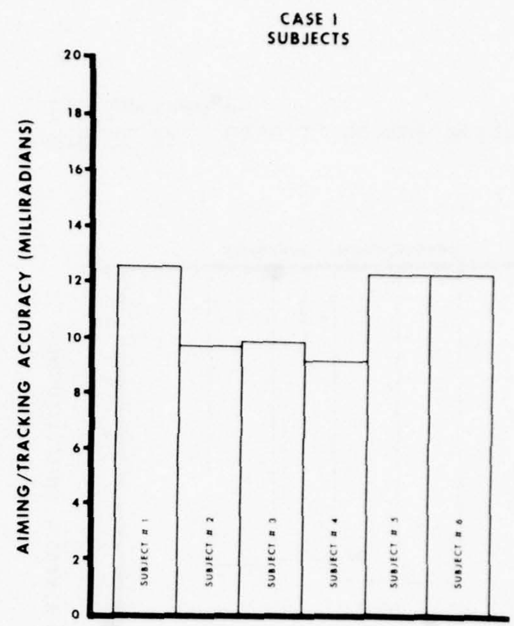


FIGURE 24. Case I, Subjects

The eye dominance x subject data (Figure 25) illustrates the statistically significant interaction between the two factors ($p < 0.001$).

Subjects 1, 3, and 5 performed better with the dominant eye and subjects 2, 4, and 6 performed better with the non-dominant eye. The helmet weighting x subject interaction (Figure 26) was also statistically significant ($p < 0.001$).

Subjects 2, 3, 4, and 6 performed better with the symmetrically weighted helmet while subjects 1 and 5 performed better with the asymmetrically weighted helmet.

The target speed x subject data is shown in Figure 27. The interaction is statistically significant ($p < 0.001$).

The maximum aiming/tracking error for all subjects is at most 4.25 mr for the static condition. The errors for the test target speed condition range from 6.4 mr to 12.4 mr; the low data ranges from 11.3 mr to 15.5 mr; and the high data from 14.1 mr to 18.9 mr. The overlapping ranges contribute to the statistical significance of the interactions.

The three-way interactions, target speed x eye dominance x subjects and target speed x helmet weighting x subjects, are not statistically significant (Figures 28 through 35).

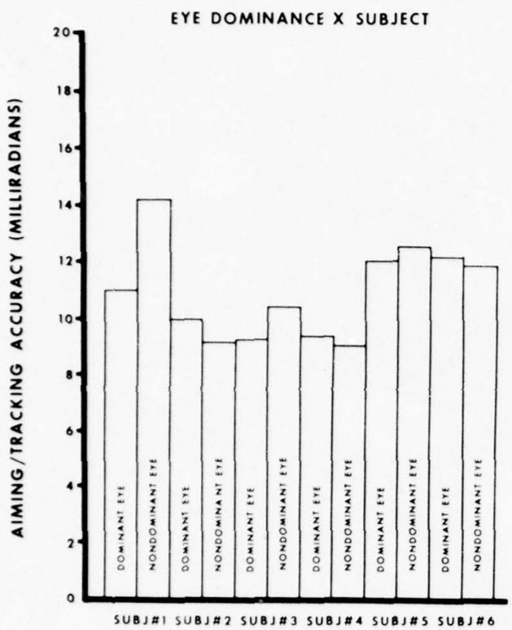


FIGURE 25. Eye Dominance X Subject

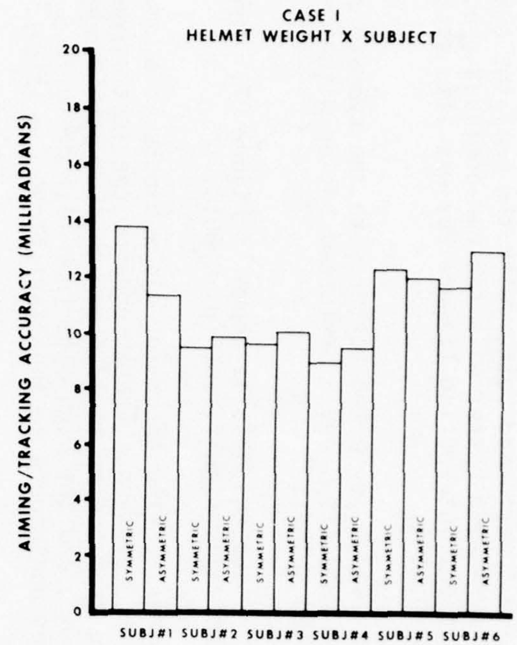


FIGURE 26. Case I, Helmet Weight X Subject

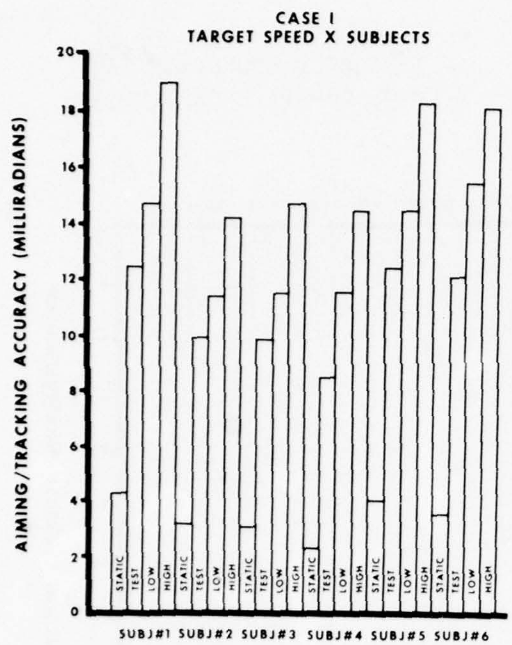


FIGURE 27. Case I, Target Speed X Subjects

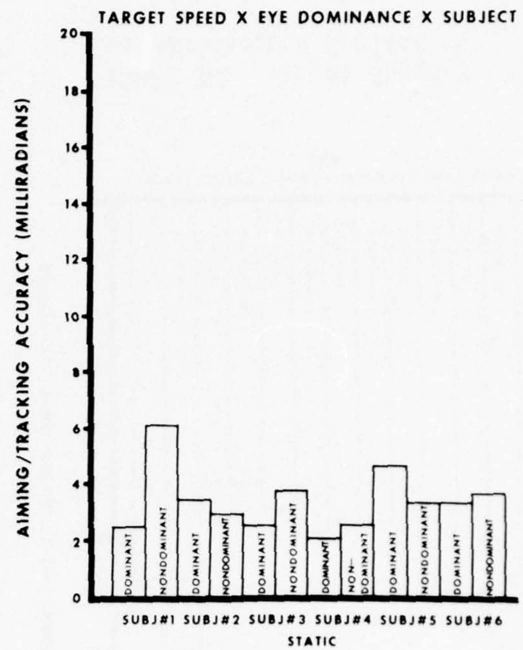


FIGURE 28. Target Speed X Eye Dominance X Subject Static

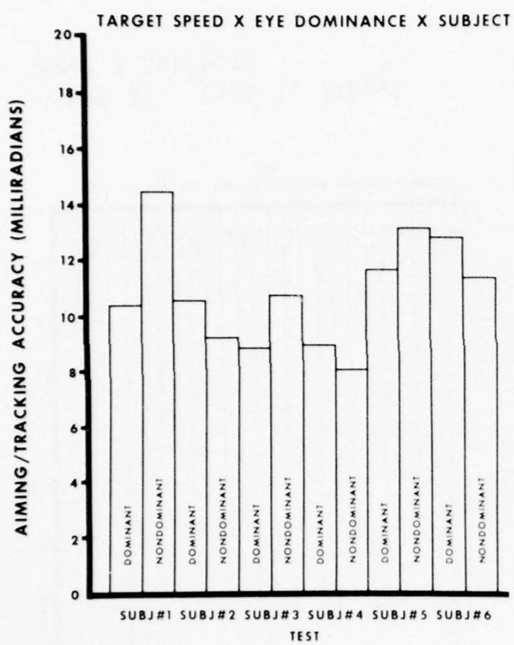


FIGURE 29. Target Speed X Eye Dominance X Subject - Test

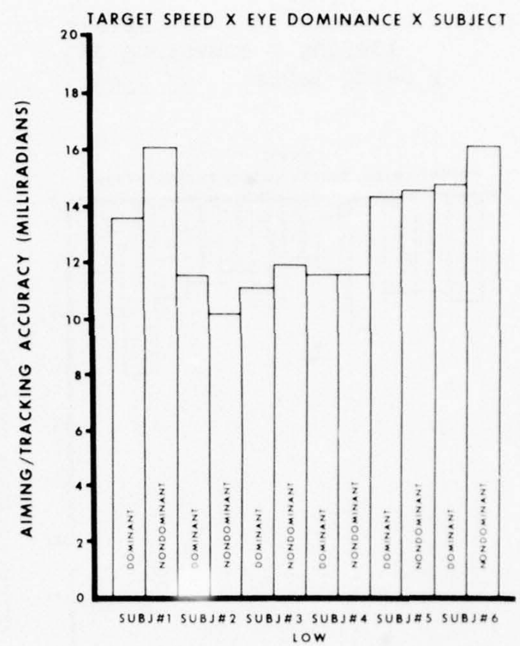


FIGURE 30. Target Speed X Eye Dominance X Subject - Low

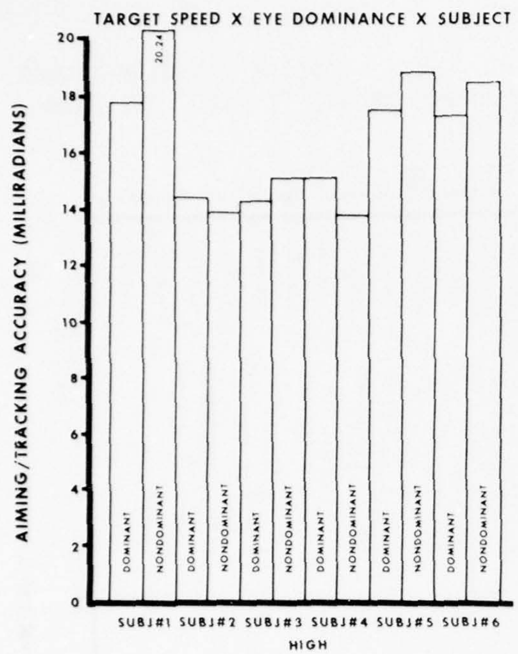


FIGURE 31. Target Speed X Eye Dominance X Subject - High

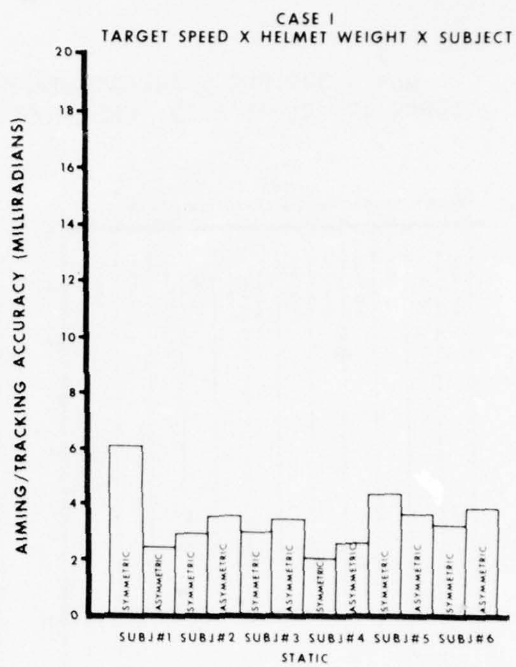


FIGURE 32. Case I, Target Speed X Helmet Weight X Subject - Static

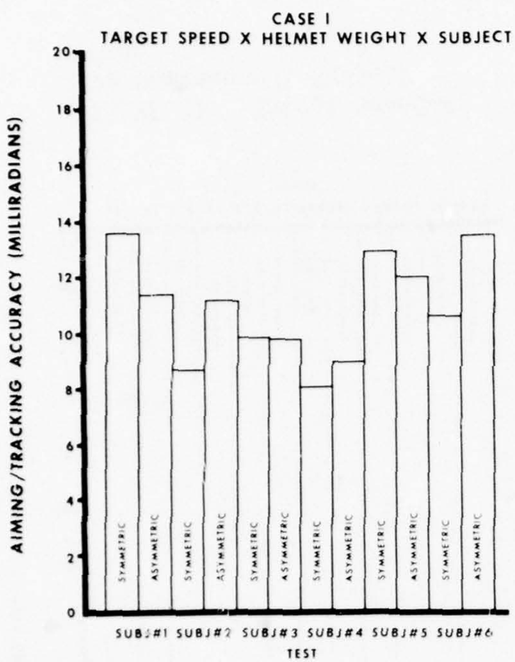


FIGURE 33. Case I, Target Speed X Helmet Weight X Subject- Test

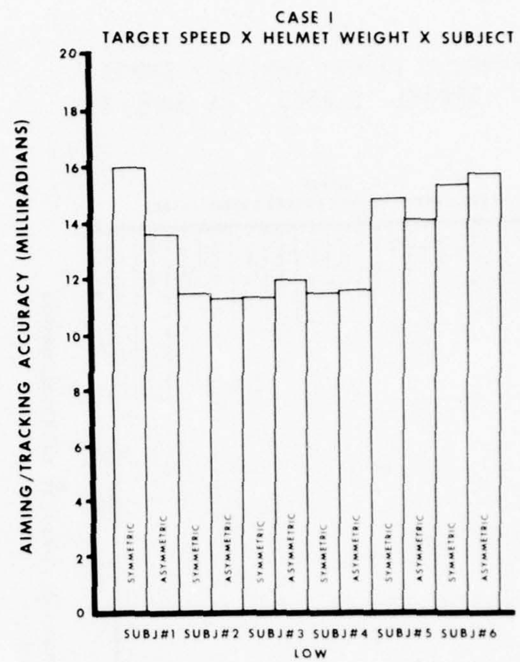


FIGURE 34. Case I, Target Speed X Helmet Weight X Subject - Low

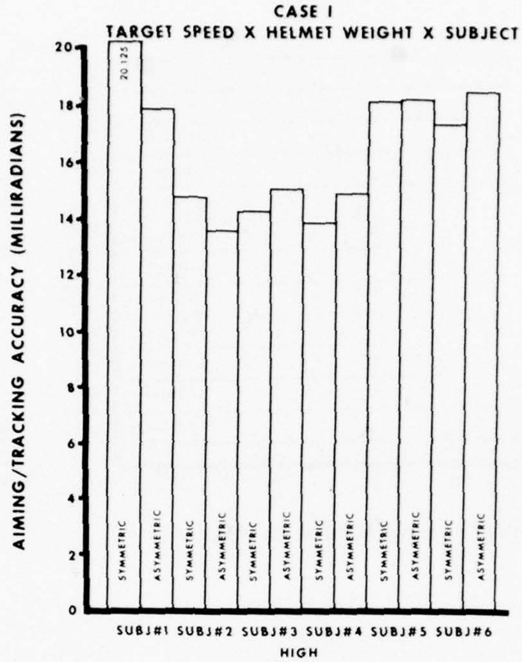


FIGURE 35. Case I, Target Speed X Helmet Weight X Subject - High

The variability attributed to target speed overshadows the less consistent differences attributable to the other factors in these interactions. The eye dominance x helmet weighting x subject interaction (Figures 36 and 37) is statistically significant ($p < 0.001$) because some subjects performed their best with the helmet weighting and eye configuration with which other subjects performed their worst.

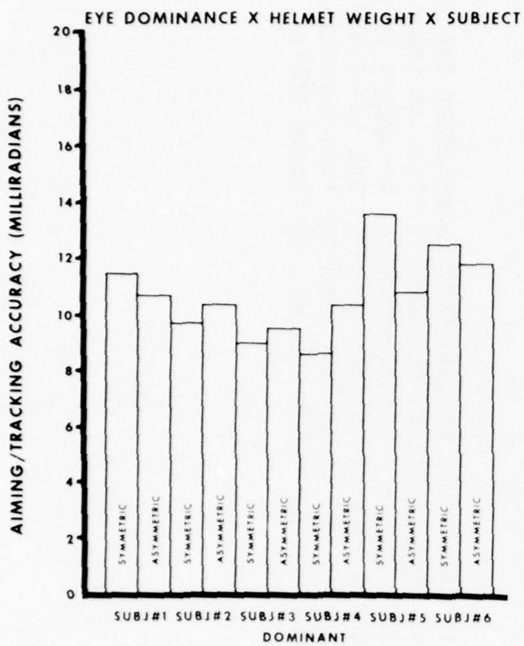


FIGURE 36. Eye Dominance X Helmet Weight X Subject - Dominant

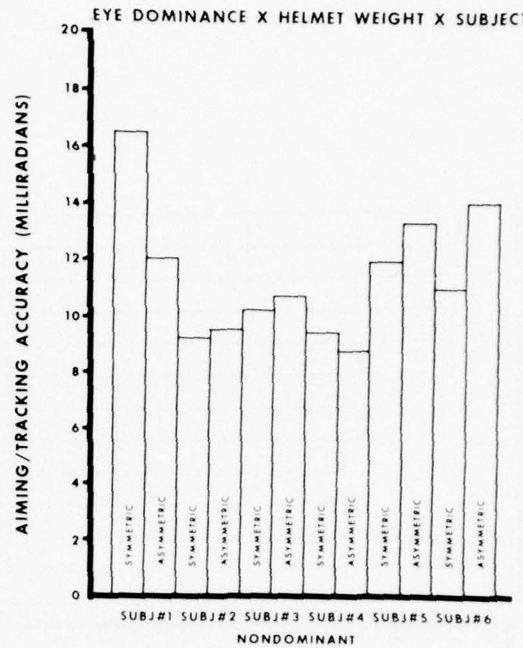


FIGURE 37. Eye Dominance X Helmet Weight X Subject - Nondominant

For example, subjects 1 and 5 performed best with dominant eye, asymmetric weighting. Subjects 2 and 4 performed their worst with the same combination. The inconsistent performance by subjects across other factors is the reason for the statistical significance.

The same rationale is applicable to the eye dominance x subject x helmet weighting x target speed interaction (Figures 38 through 41).

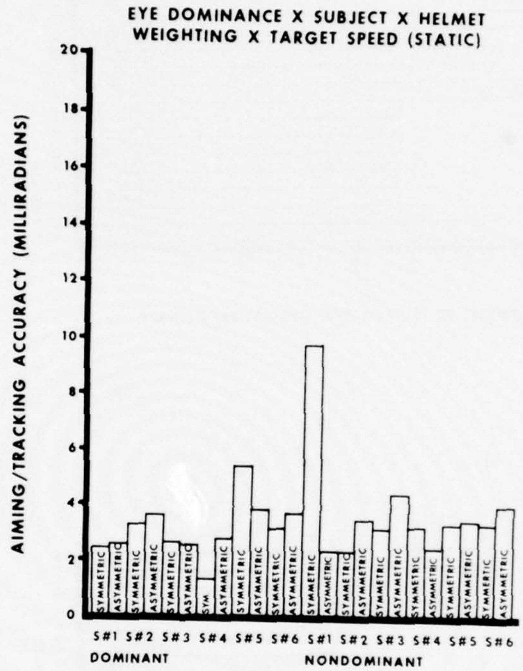


FIGURE 38. Eye Dominance X Subject X Helmet Weighting X Target Speed (Static)

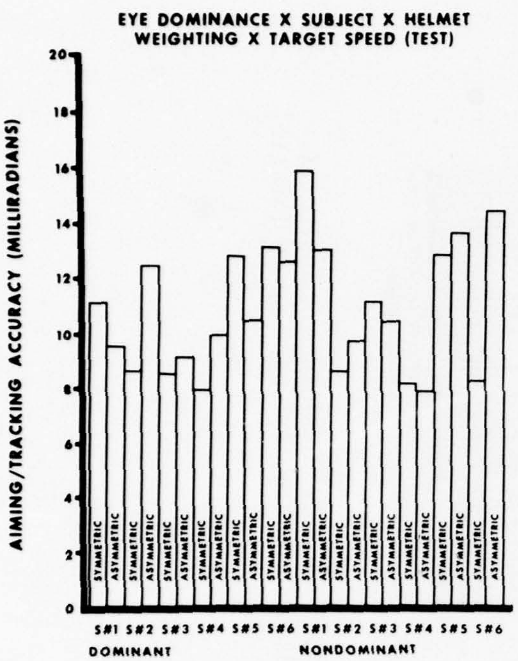


FIGURE 39. Eye Dominance X Subject X Helmet Weighting X Target Speed (Test)

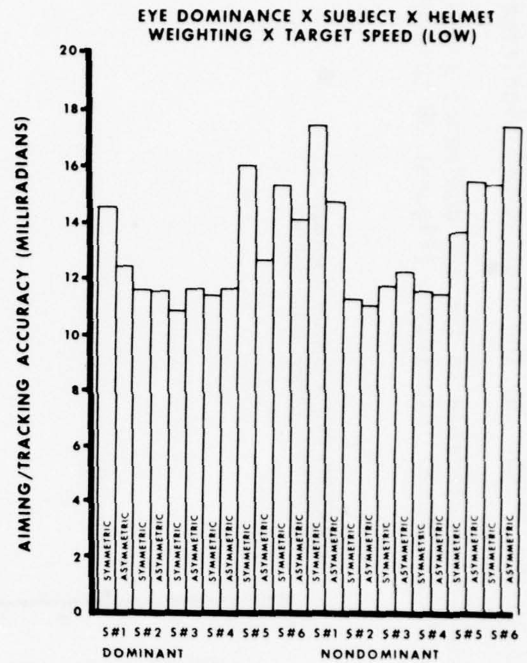


FIGURE 40. Eye Dominance X Subject X Helmet Weighting X Target Speed (Low)

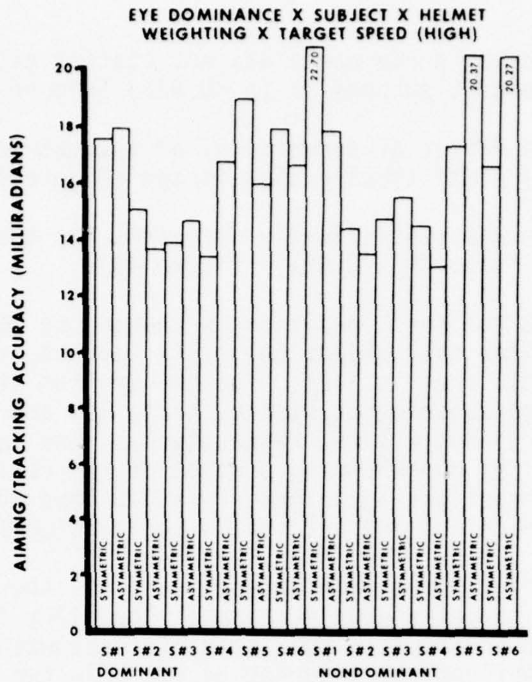


FIGURE 41. Eye Dominance X Subject X Helmet Weighting X Target Speed (High)

This interaction is also statistically significant ($p < 0.001$); the variability attributed to the target speed factor is predictable and consistent; the variability attributed to the subject factor is not predictable or consistent. This inconsistency is important to note from a practical viewpoint. We knew a priori that people were different, but we did not know that each subject would have a preferred helmet configuration, i.e., that which provided the greatest accuracy--not that which subjectively pleased the subject most.

CASE II

The aiming/tracking performance was not statistically different with the sling or formfit suspension ($p < 0.321$) (Figure 42).

Neither was the effect of symmetrical or asymmetrical helmet weighting ($p < 0.224$) statistically significant (Figure 43).

The performance was statistically different for the four levels of the target speed factor ($p < 0.001$) (Figure 44).

The accuracy at the test condition is changed by 266% from the static condition. When the subject begins to vibrate, the accuracy change from the static case is 338%. The change from static to high is 455%. The average accuracy at static, test, low and high is 3.5 mr, 10.6 mr, 12.7 mr, and 16.1 mr, respectively. The target speed factor accounted for an overwhelming portion of the variation of the means. The interactions again have F ratios less than one; therefore, the interactions are not statistically significant.

The target speed x suspension data (Figure 45) show a reduction in accuracy as target speed increases. The sling suspension seems to be better than formfit, but the difference was not statistically significant and the interaction of these two factors is not statistically significant ($p < .989$). The target speed x helmet weighting data (Figure 46) show also a reduction in accuracy as target speed increases.

The symmetric performance seems to be better than the asymmetric performance, but the difference was not statistically significant. The helmet weighting x helmet suspension data (Figure 47) show the accuracy about the same for the symmetric and asymmetric formfit sling suspensions.

The target speed x helmet weighting x suspension interaction is not significant ($p < 0.56$). The data (Figure 48) show the overwhelming effects of the target speed factors and overshadows the differences contributed by the other factors.

The interaction is statistically significant ($p < 0.001$). The conditions which led to the best aiming/tracking performance for some subjects resulted in the worst conditions for others. This situation is important to consider from a practical viewpoint as discussed in Case I. If some subjects perform best using a specific helmet configuration and others perform their best using a different configuration, the designers should not expect one of the designs to be most efficient for all individuals.

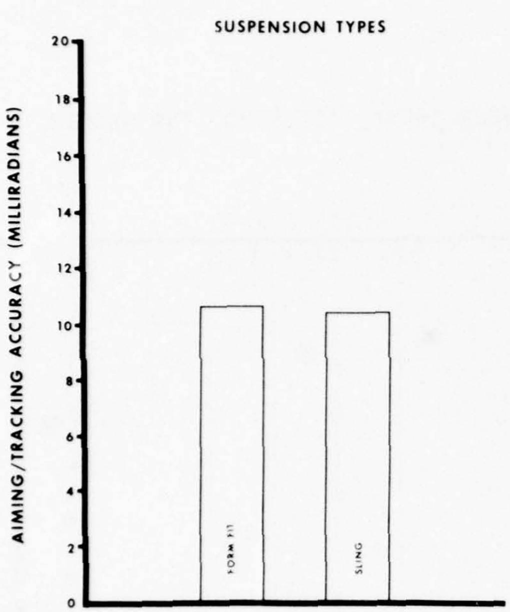


FIGURE 42. Suspension Types

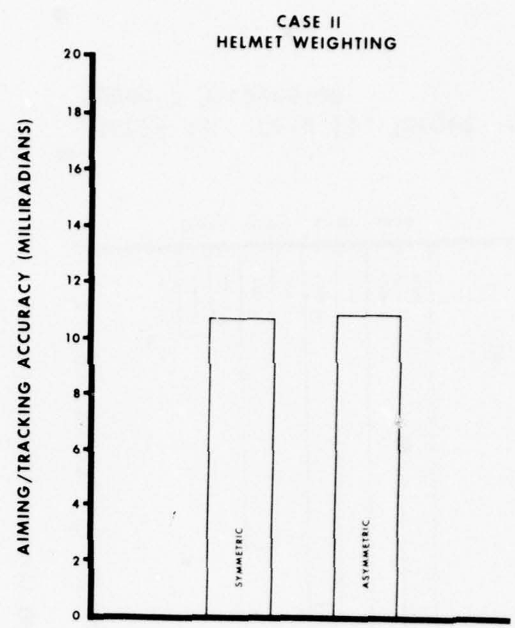


FIGURE 43. Case II, Helmet Weighting

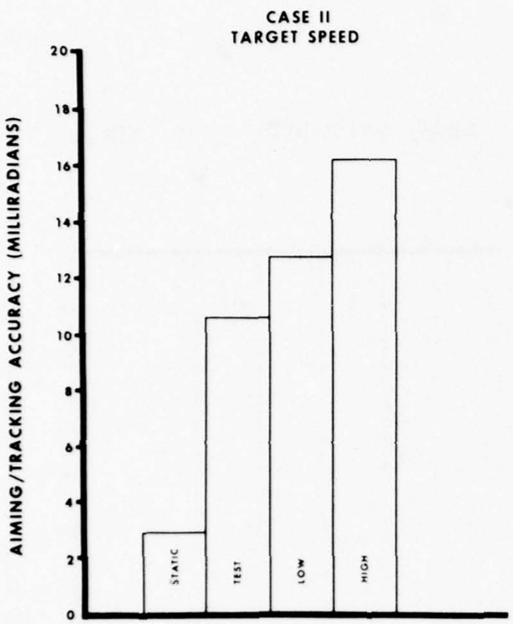


FIGURE 44. Case II, Target Speed

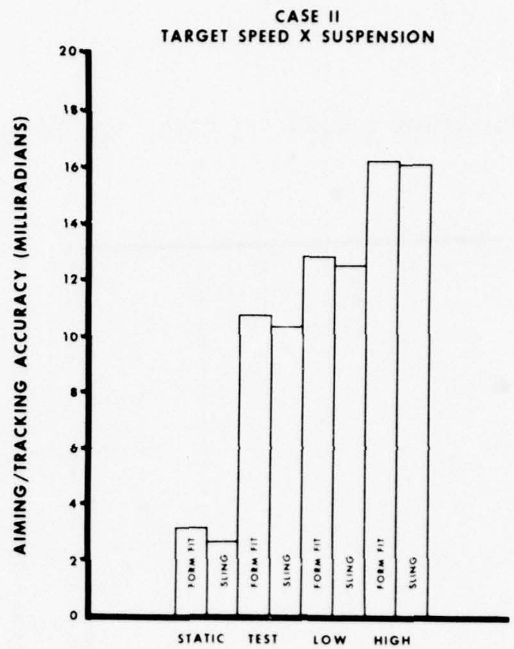


FIGURE 45. Case II, Target Speed X Suspension

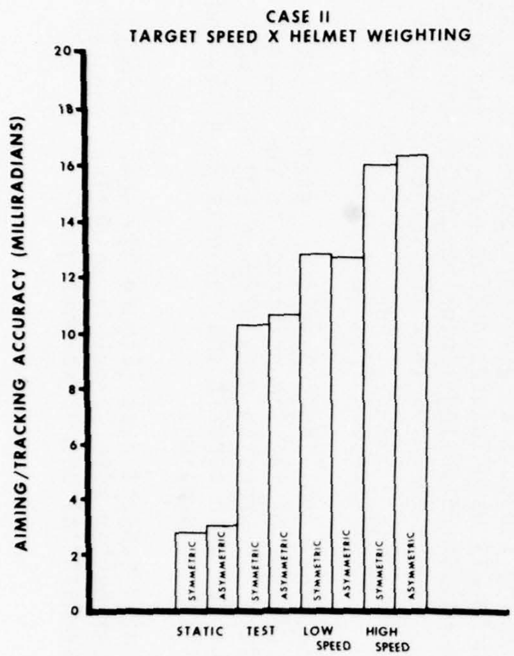


FIGURE 46. Case II, Target Speed X Helmet Weighting

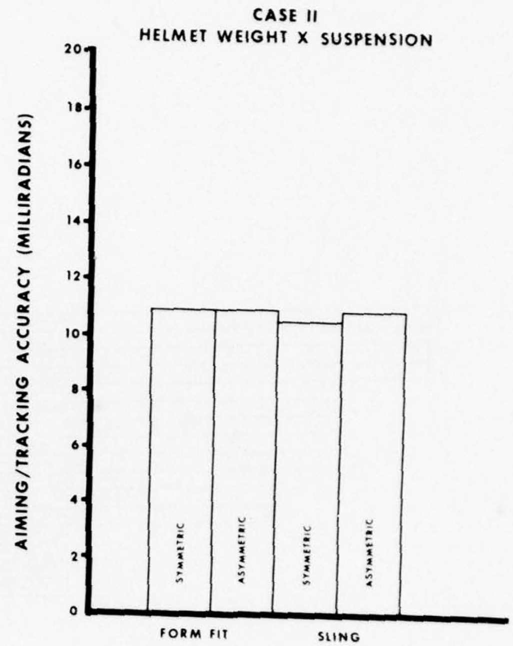


FIGURE 47. Case II, Helmet X Suspension

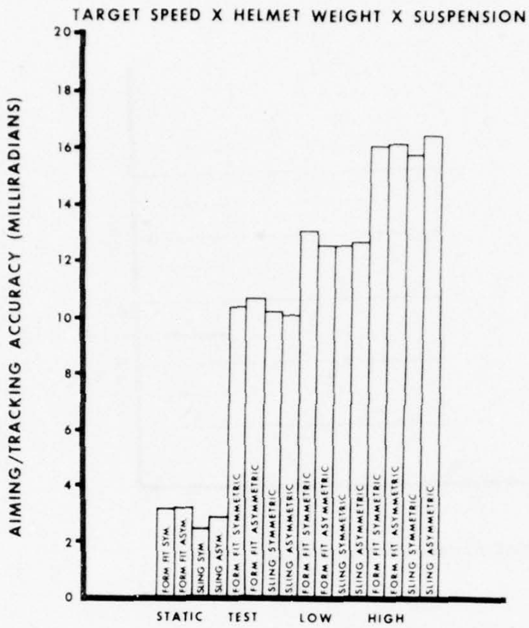


FIGURE 48. Target Speed X Helmet Weight X Suspension

The analysis with subjects as a factor will now be discussed. The same rationale for using subjects as a factor applies as in Case I. When the subject factor is used to account for more of the within cells variation, the helmet weighting factor becomes statistically significant ($p < 0.009$). Figure 49 shows that the subjects do perform differently ($p < 0.001$), as in Case I (Figure 24). The range is from 9.0 mr to 11.7 mr, a 30% difference from best to worst.

The two-way interactions involving subjects are statistically significant ($p < 0.001$) because of the inconsistency in the subject performances. The subject x suspension data (Figure 50) show subjects 1 and 3 perform better with formfit and subjects 2, 4, 5, and 6 perform better with sling suspension.

The helmet weighting x subject data (Figure 51) show subjects 1, 2, 3, 4, and 6 perform better with symmetric weighting; subject 5 performs best with asymmetrical helmet weighting.

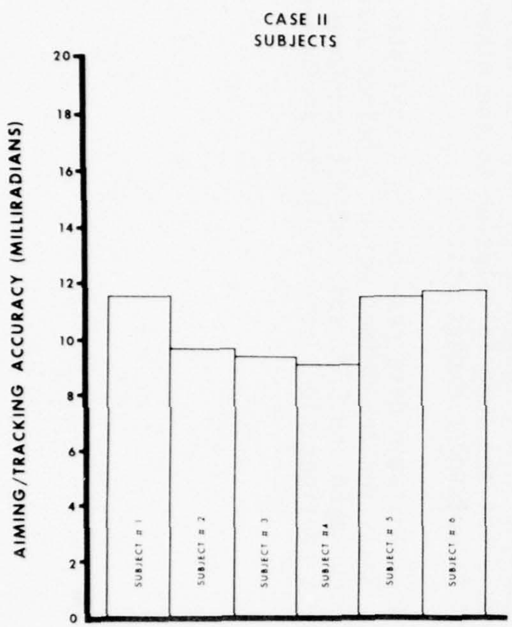


FIGURE 49. Case II, Subjects

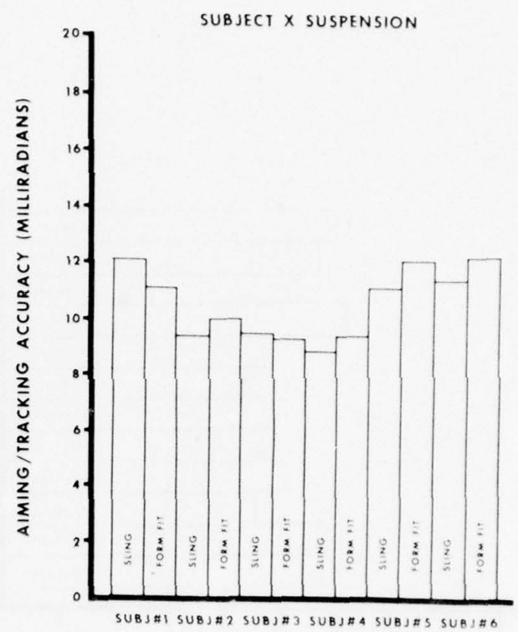


FIGURE 50. Subject X Suspension

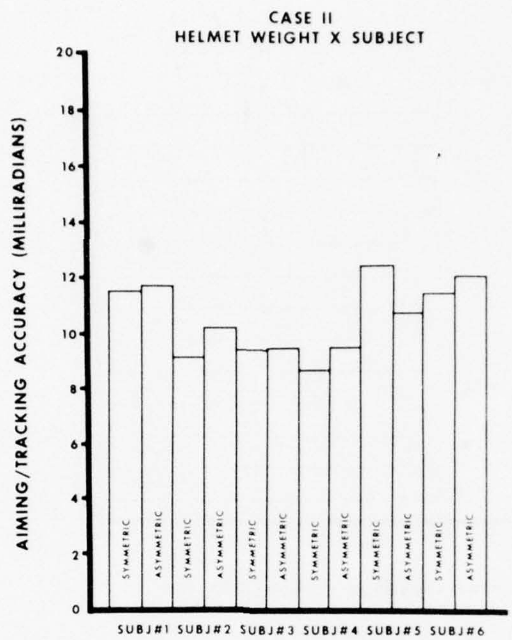


FIGURE 51. Case II, Helmet Weight X Subject

The target speed x subject data (Figures 52 through 55) indicate each subject performs about the same in relation to the other subjects at all levels of target speed except static.

This inconsistency in the static data resulted in a statistically significant interaction. Analyzing the helmet weight x helmet suspension x subject data (Figures 56 and 57), some subjects performed better with the same helmet configuration; other subjects performed worse.

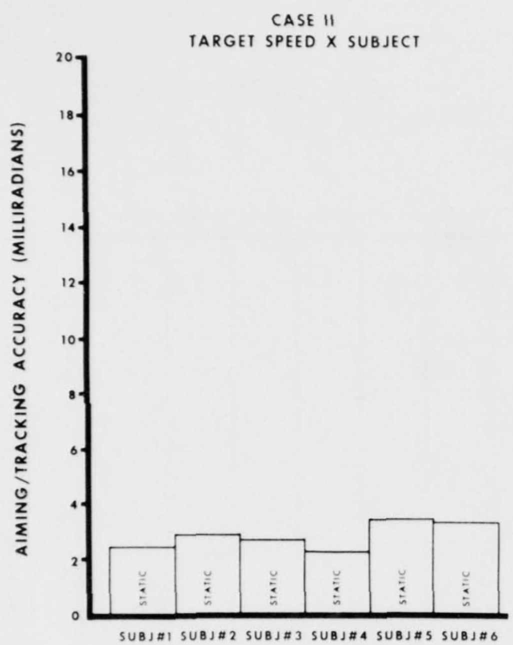


FIGURE 52. Case II, Target Speed X Subject (Static)

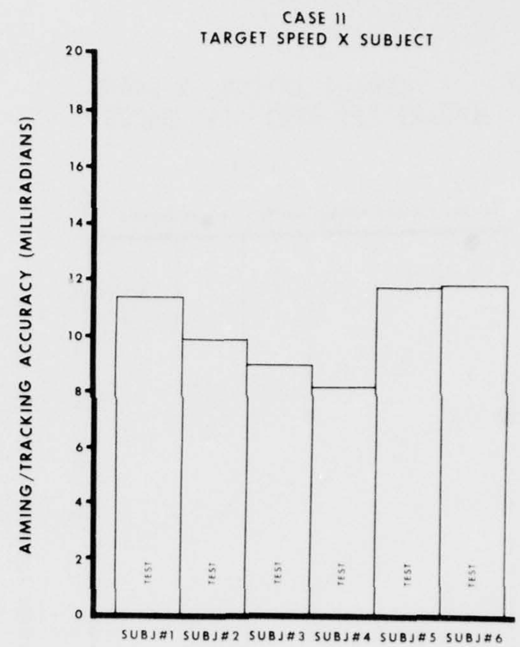


FIGURE 53. Case II, Target Speed X Subject (Test)

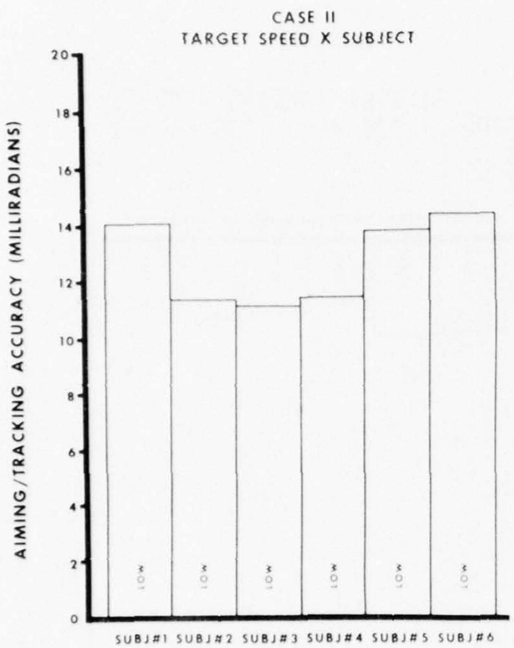


FIGURE 54. Case II, Target Speed X Subject (Low)

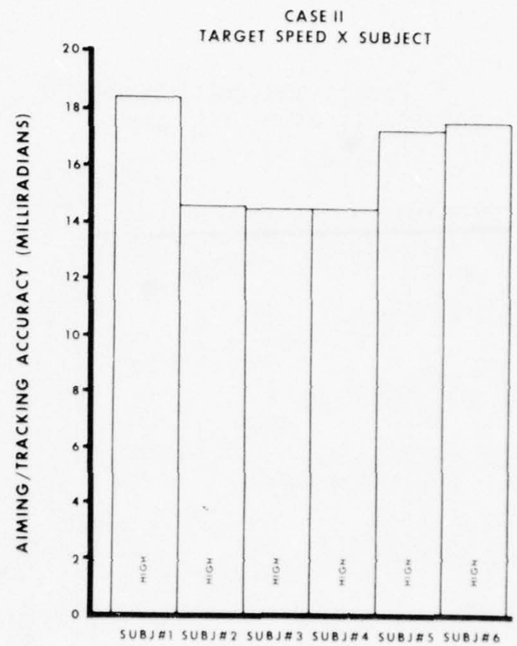


FIGURE 55. Case II, Target Speed X Subject (High)

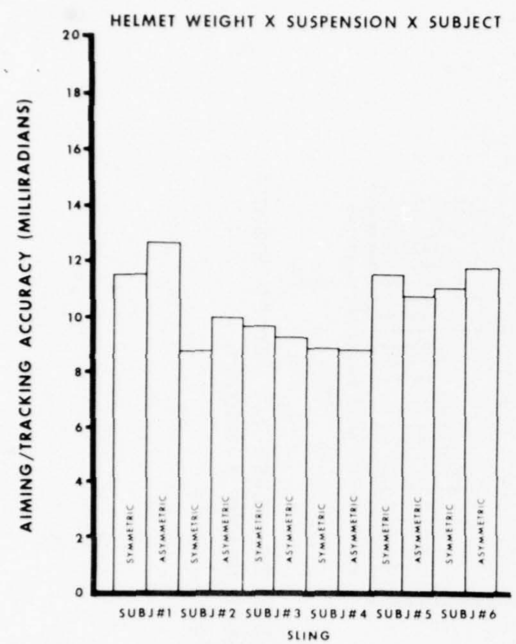


FIGURE 56. Helmet Weight X Suspension X Subject (Sling)

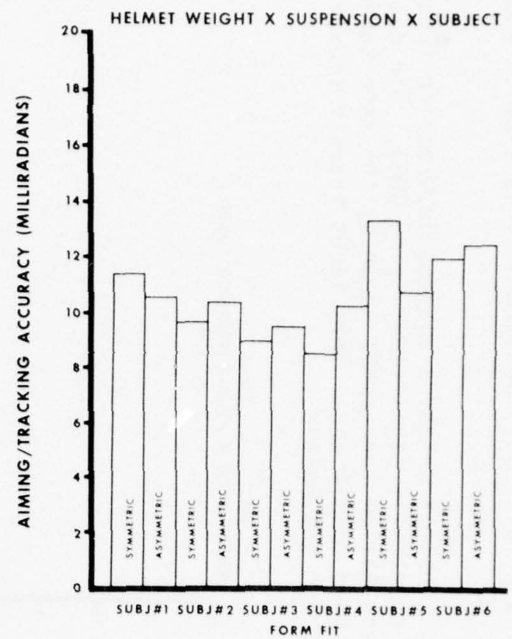


FIGURE 57. Helmet Weight X Suspension X Subject (Form Fit)

Subject 1 performed best with asymmetric formfit while subject 3 performed worse with the same configuration. This interaction is statistically significant ($p < 0.001$) because of this type of inconsistent performance.

The target speed x helmet weight x subject interaction (Figures 58 through 61) is statistically significant ($p < 0.005$). The data for the static speed do not follow the trends shown by the same subject at the other target speed conditions. This inconsistency causes the statistically significant interaction.

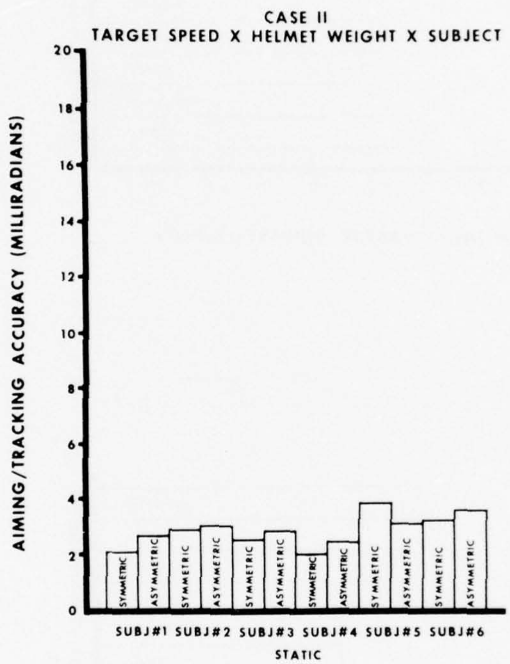


FIGURE 58. Case II, Target Speed X Helmet Weight X Subject (Static)

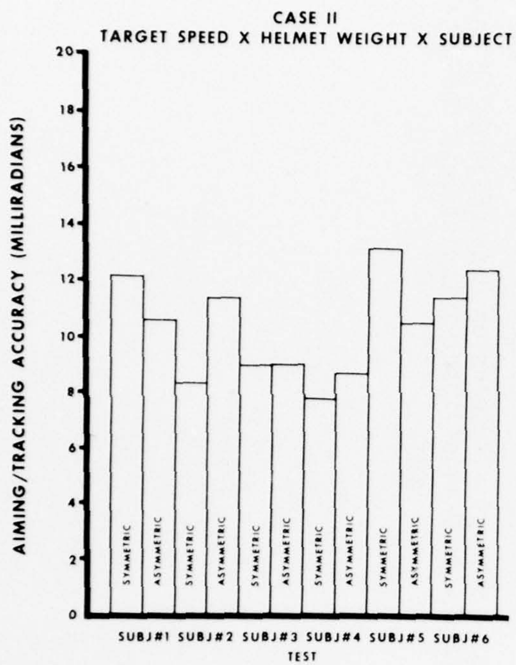


FIGURE 59. Case II, Target Speed X Helmet Weight X Subject (Test)

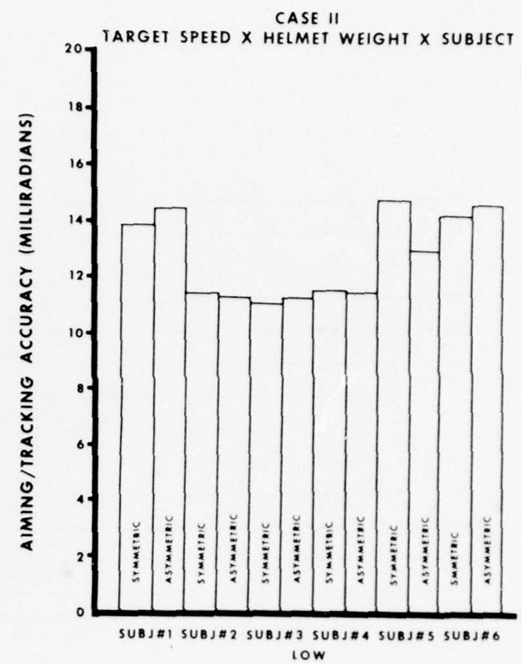


FIGURE 60. Case II, Target Speed X Helmet Weight X Subject (Low)

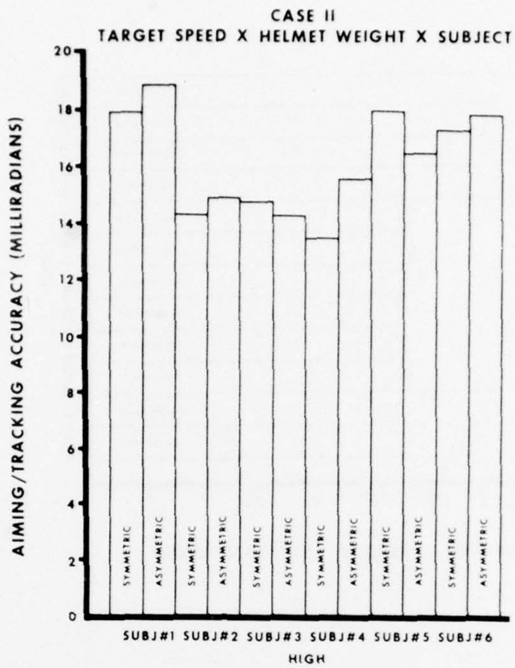


FIGURE 61. Case II, Target Speed X Helmet Weight X Subject (High)

The target speed x subject x suspension data (Figures 62 through 65) did not show statistically significant interactions; the data are consistent.

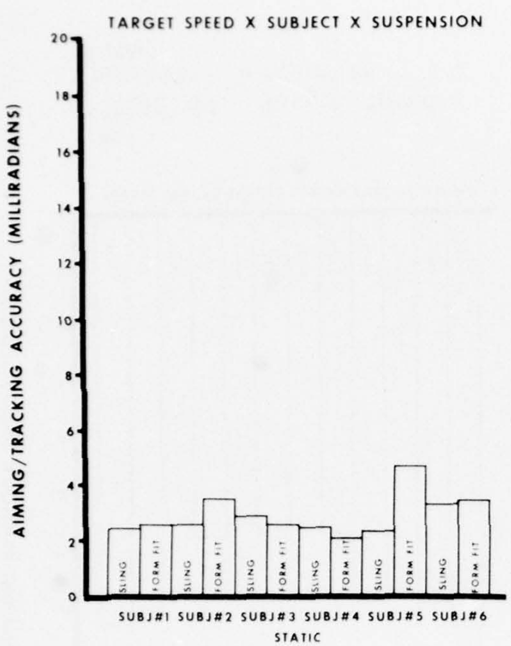


FIGURE 62. Target Speed X
Subject X Suspension
(Static)

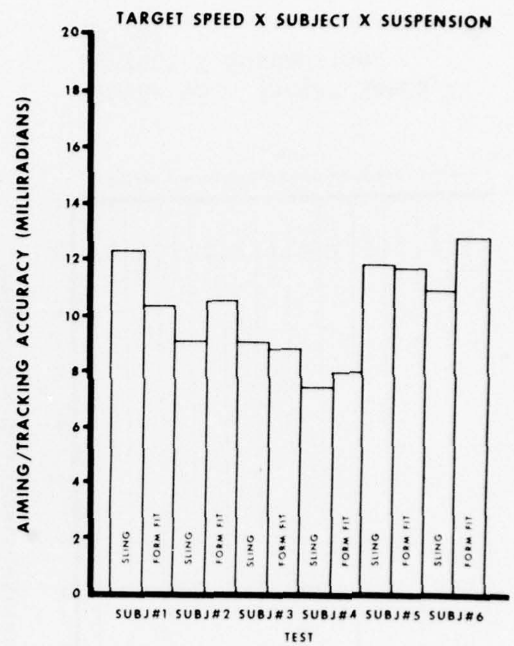


FIGURE 63. Target Speed X
Subject X Suspension
(Test)

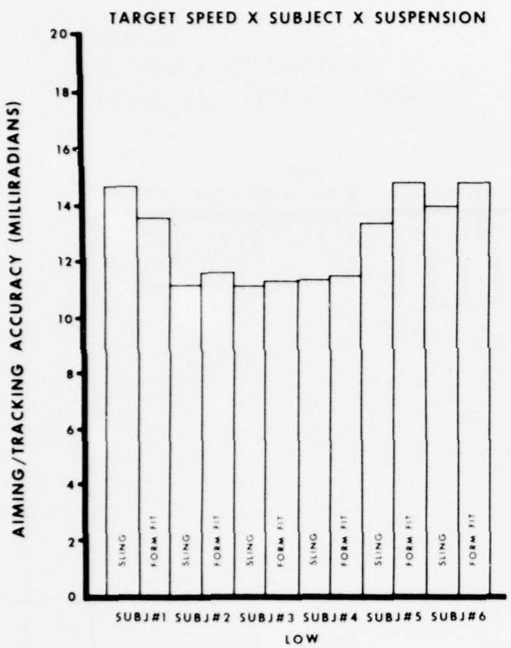


FIGURE 64. Target Speed X Subject X Suspension (Low)

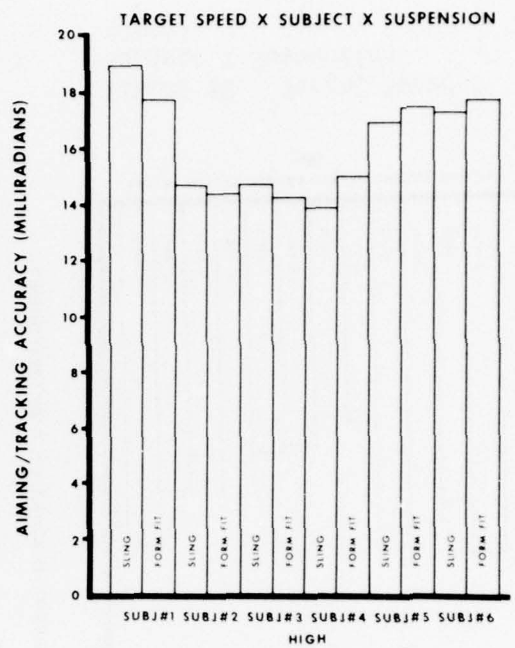


FIGURE 65. Target Speed X Subject X Suspension (High)

The suspension x subject x helmet weighting x target speed data are presented in Figures 66 through 69.

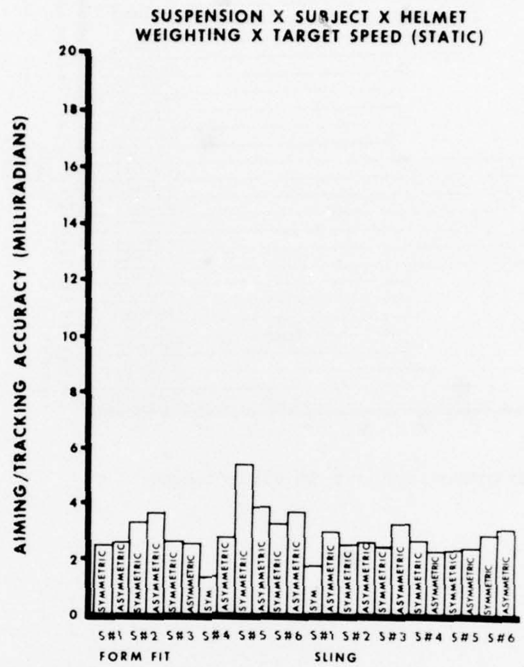


FIGURE 66. Suspension X Subject X Helmet Weighting X Target Speed (Static)

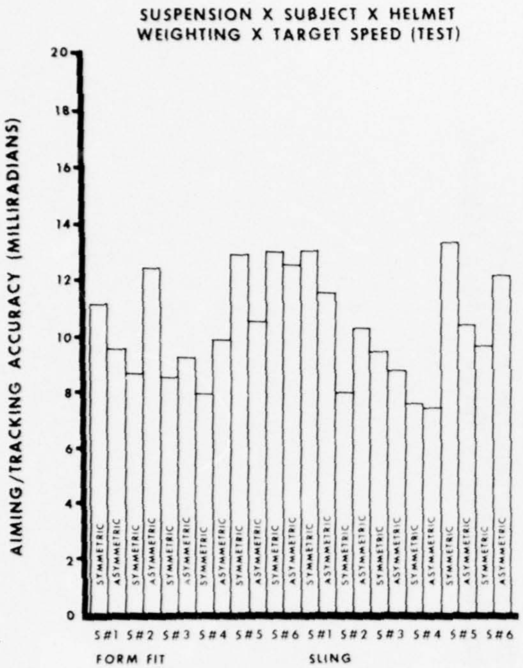


FIGURE 67. Suspension X Subject X Helmet Weighting X Target Speed (Test)

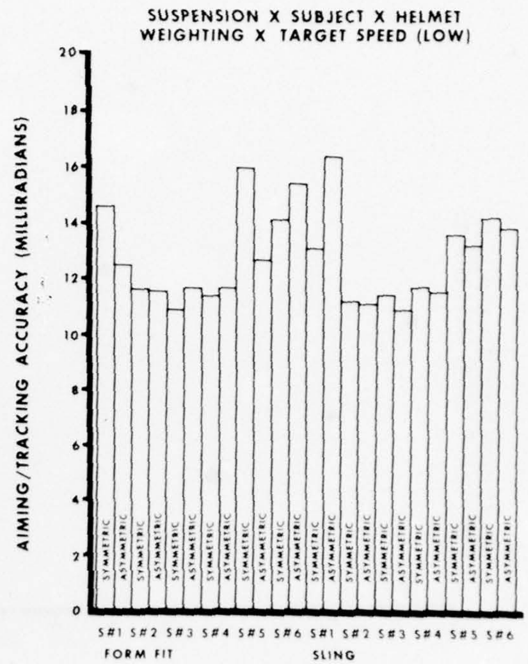


FIGURE 68. Suspension X Subject X Helmet Weighting X Target Speed (Low)

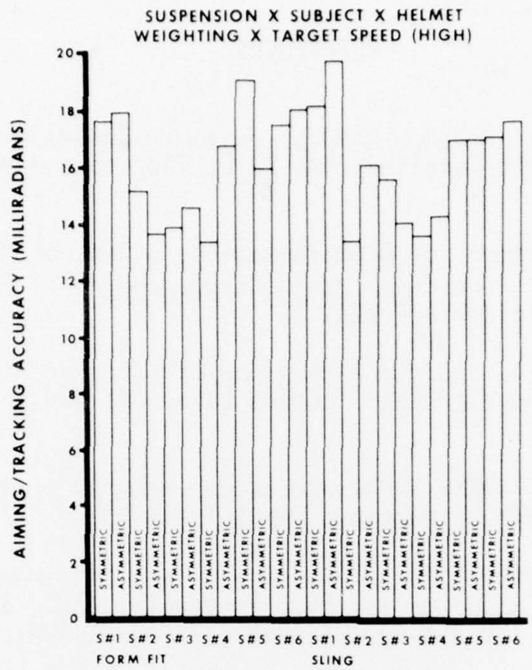


FIGURE 69. Suspension X Subject X Helmet Weighting X Target Speed (High)

CONCLUSIONS

Even though some factors were statistically significant, the only factor showing practical significance was target speed. The data obtained at each of the four levels of this factor are of considerable practical interest. The basic head aiming error of about 3 mr (pooling all other factors) is an important human performance capability to quantify. This error increases drastically as the subject is required to track the moving target; the tracking error increases by more than 250%. Unfortunately, data were not collected with the target static and the subject vibrating. The additional error contributed by the subject vibrating, in addition to the target moving at 4^0/second, amounts to only about 20%. The psychomotor demands of tracking a target with overt head motions seem to be much more demanding than simply aiming at a fixed target. The additional instability attributed to the vibration added only 20% error. The additional error added by moving the target twice the rate (from 4^0/second to 8^0/second) is about 26%.

REFERENCES

Cramer, E. M. 1974. *Revised MANOVA program.* Chapel Hill, NC: The University of North Carolina, The L. L. Thurstone Psychometric Laboratory.

Dixon, E. W. (Department of Biomathematics, School of Medicine, Los Angeles). 1973. *Biomedical statistical programs.* Los Angeles, CA: University of California Press.

Grossman, J. D. 1974. *Flight evaluation of pilot sighting accuracy using a helmet-mounted sight.* China Lake, CA: Naval Weapons Center. TR NWC TP 5638.

Haywood, W. J., Jr. 1975. *Advanced helmet mounted sight study program.* Bedford, MA: Raytheon Company. AMRL-TR-73-10.

Nicholson, R. M. 1965. *The feasibility of a helmet-mounted sight as a control device.* Minneapolis, MN: Honeywell, Inc., Systems and Research Division. HD-55B-53. (Summary in *Human Factors*, 1966 October).

Polhemus, W. L. 1976. *An advanced helmet mounted sight (AHMS) system Nov 71 - Apr 73.* Burlington, VT: Polhemus Navigation Sciences, Inc. AMRL-TR-73-47.

Polhemus, W. L. 1975. *Micro-tracker.* Presented at the Second Advanced Aircrew Display Symposium; 23-24 April 1975; Patuxent River, MD: Naval Air Test Center.

Sawamura, R. 1976. *Advanced helmet-mounted sight Dec 70 - Jun 72.* Minneapolis, MN: Honeywell, Inc. ARML-TR-73-9.

APPENDIX A

EYE DOMINANCE TEST
By
Isaac Behar, Ph.D.

APPARATUS

A modified Dyer sighting ocular dominance test was used. This consisted of a black matte board, 24-inches wide by 19 1/4-inches high which had a centered rectangular opening, 3/4-inches wide by 2-inches high. Extending away from the opening was a 2x2x22 inch long parallelepiped black tube which had at its far end two cutout forms, a circle and a triangle. Each cutout was covered with Polaroid HN-32 polarizer, but with orthogonal axes of orientation. A second component consisted of a pair of goggles in which each eye lens was replaced with polarizers, again with orthogonal axes. When the goggles were worn and the distal end of the tube sighted through the opening, only one of the two forms was seen. When the opening to the tube was aligned with the right eye, the triangle was seen; when alignment was with the left eye, the circle was seen.

PROCEDURE

While the observer wore the polarizing goggles, the eye dominance test board was placed in front of him below waist level. He was instructed to grasp the board with both hands, lift it to eye level, view through the opening, and report which form was clearly visible. This was repeated three times with instruction to hold the board at arms length, mid position, and close to the face.

RESULTS

Subject 1 - Left eye dominant (weak)

Subject 2 - Right eye dominant

Subject 3 - Left eye dominant

Subject 4 - Right eye dominant

Subject 5 - Left eye dominant

Subject 6 - Right eye dominant

APPENDIX B

HELMET CENTER OF GRAVITY (CG) DETERMINATION

By

Ted Hundley, M.E.

Two helmet conditions relative to CG location were to be tested. The first condition was to be with the helmet CG located at a point corresponding to the CG location of a regular size SPH-4 helmet with normal offset due to suspension adjustment. The second condition was to be the addition of a one pound weight mounted on the lower exterior part of the helmet shell.

Previous measurements using a test device belonging to Dayton T. Brown Corporation had established a CG location for the SPH-4 regular size helmet. This device uses an AFL-3 medium size head form which is balanced about a point representing the CG location of a fiftieth percentile adult male's head and neck. All helmet CG measurements will be referred to an axis system using this point as its origin. Defining a three axis coordinate system originating at the balance point with the positive X-axis exiting through the face, the positive Y-axis exiting through the right side of the head, and the positive Z-axis exiting through the top of the head, the coordinates for the CG location of a regular SPH-4 are as follows: X = -.72 in., Y = -.25 in., Z = +2.1 in.

Dayton T. Brown's device was not available at the time of the test, and a duplicate device being built by USAARL was not completed and tested. Therefore, an alternate method of locating the CG of the test helmet at the desired point had to be devised. The method used was a needlepoint on which a regular SPH-4 was balanced in all three planes. When a balance point in one plane was located, its position was marked on the helmet exterior. The locations of the three balance points were then transferred to the test helmet. Counterweights were then added to the test helmet until it was balanced about the transferred points. Thus, the CG of the test helmet was made to conform to that of a regular SPH-4.

The shift in location of the helmet CG due to the addition of the eccentric weight was determined by calculations. The physical location of the eccentric weight on the helmet was measured in relation to known points and then transferred to a drawing showing the physical location of the helmet elements to a fiftieth percentile head-neck CG location. This located the CG of the eccentric weight in relation to the CG of the head-neck. The resultant CG location of the helmet and the eccentric weight were calculated to be: X = -.50 in., Y = +1.03 in., Z = +1.47 in.

DISTRIBUTION LIST FOR USAARL LABORATORY REPORTS

Defense Documentation Center
Alexandria, VA 22314 (12)

Director of Defense Research and Engineering
ATTN: Assistant Director (Environmental and Life Sciences)
Washington, DC 20301 (1)

Uniform Services University of the Health Sciences
4301 Jones Bridge Road
Bethesda, MD 20014 (1)

Commander
US Army Medical Research and Development Command
ATTN: SGRD-AJ (Mrs Madigan)
Fort Detrick
Frederick, MD 21701 (5)

Redstone Scientific Information Center
DRDMI-TBD
US Army Missile R&D Command
Redstone Arsenal, AL 35809 (1)

US Army Yuma Proving Ground
Technical Library
Yuma, AZ 85364 (1)

US Army Aviation Engineering Flight Activity
ATTN: DAVTE-M (Technical Library)
Edwards AFB, CA 93523 (1)

US Army Combat Developments Experimentation Command
Technical Library
HQ, USACDEC
Box 22
Fort Ord, CA 93941 (1)

Aeromechanics Laboratory
US Army Research & Technology Labs
Ames Research Center, M/S 215-1
Moffett Field, CA 94035 (1)

Sixth United States Army
ATTN: SMA
Presidio of San Francisco, California 94129 (1)

Director
Army Audiology & Speech Center
Walter Reed Army Medical Center
Forest Glen Section, Bldg 156
Washington, DC 20012 (1)

US Army Materiel Command
Harry Diamond Laboratories
Scientific & Technical Information Offices
2800 Powder Mill Road
Adelphi, MD 20783 (1)

US Army Ordnance Center & School
Library, Bldg 3071
ATTN: ATSL-DOSL
Aberdeen Proving Ground, MD 21005 (1)

US Army
Environmental Hygiene Agency
Library, Bldg E2100
Aberdeen Proving Ground, MD 21010 (1)

Technical Library
Chemical Systems Laboratory
Aberdeen Proving Ground, MD 21010 (1)

US Army Materiel Systems Analysis Agency
ATTN: Reports Distribution
Aberdeen Proving Ground, MD 21005 (1)

Director
Biomedical Laboratory
Aberdeen Proving Ground, MD
21010 (1)

HDQ, First United States Army
ATTN: AFKA-MD (Surgeon's Office)
Fort George G. Meade, MD
20755 (1)

Director
Ballistic Research Laboratory
ATTN: DRDAR-TSB-S (STINFO)
Aberdeen Proving Ground, MD
21005 (2)

US Army Research & Development
Technical Support Activity
Fort Monmouth, NJ 07703 (1)

CDR/DIR
US Army Combat Surveillance &
Target Acquisition Laboratory
ATTN: DELCS-D
Fort Monmouth, NJ 07703 (1)

US Army Avionics R&D Activity
ATTN: DAVAA-O
Fort Monmouth, NJ 07703 (1)

US Army White Sands Missile Range
Technical Library Division
White Sands Missile Range
New Mexico 88002 (1)

Chief
Benet Weapons Laboratory
LCWSL, USA ARRADCOM
ATTN: DRDAR-LCB-TL
Watervliet Arsenal
Watervliet, NY 12189 (1)

US Army Research & Technology Labs
Propulsion Laboratory MS 77-5
NASA Lewis Research Center
Cleveland, OH 44135 (1)

US Army Field Artillery School
Library
Snow Hall, Room 16
Fort Sill, OK 73503 (1)

US Army
Dugway Proving Ground
Technical Library
Bldg 5330
Dugway, UT 84022 (1)

US Army Material Development &
Readiness Command
ATTN: DRCSG
5001 Eisenhower Avenue
Alexandria, VA 22333 (1)

US Army Foreign Science & Technology
Center
ATTN: DRXST-IS1
220 7th St., NE
Charlottesville, VA 22901 (1)

US Army Training & Doctrine Command
ATTN: ATCD
Fort Monroe, VA 23651 (2)

Commander
US Army Training & Doctrine Command
ATTN: Surgeon
Fort Monroe, VA 23651 (1)

US Army Research & Technology Labs
Structures Laboratory Library
NASA Langley Research Center
Mail Stop 266
Hampton, VA 23665 (1)

Commander
10th Medical Laboratory
ATTN: DEHE (Audiologist)
APO New York 09180 (1)

Commander
US Army Natick R&D Command
ATTN: Technical Librarian
Natick, MA 01760 (1)

Commander
US Army Troop Support & Aviation
Material Readiness Command
ATTN: DRSTS-W
St. Louis, MO 63102 (1)

Commander
US Army Aviation R&D Command
ATTN: DRDAV-E
PO Box 209
St. Louis, MO 63166 (1)

Director
US Army Human Engineering
Laboratory
ATTN: Technical Library
Aberdeen Proving Ground, MD
21005 (1)

Commander
US Army Aviation Research &
Development Command
ATTN: Library
PO Box 209
St. Louis, MO 63166 (1)

Commander
US Army Health Services Command
ATTN: Library
Fort Sam Houston, TX 78234 (1)

Commander
US Army Academy of Health Sciences
ATTN: Library
Fort Sam Houston, TX 78234 (1)

Commander
US Army Airmobility Laboratory
ATTN: Library
Fort Eustis, VA 23604 (1)

Air University Library (AUL/LSE)
Maxwell AFB, AL 36112 (1)

US Air Force
Flight Test Center
Technical Library, Stop 238
Edwards AFB, CA 93523 (1)

US Air Force
Armament Development & Test Center
Technical Library
Eglin AFB, FL 32542 (1)

US Air Force Institute of
Technology (AFIT/LDE)
Bldg 640, Area B
Wright-Patterson AFB, OH 45433 (1)

US Air Force
Aerospace Medical Division
School of Aerospace Medicine
Aeromedical Library/TSK-4
Brooks AFB, TX 78235 (1)

Director of Professional Services
Office of The Surgeon General
Department of the Air Force
Washington, DC 20314 (1)

Human Engineering Division
6570th Aerospace Medicine Research
Laboratory
ATTN: Technical Librarian
Wright-Patterson Air Force Base,
OH 45433 (1)

US Navy
Naval Weapons Center
Technical Library Division
Code 2333
China Lake, CA 93555 (1)

US Navy
Naval Aerospace Medical Institute
Library
Bldg 1953, Code 012
Pensacola, FL 32508 (1)

US Navy
Naval Submarine Medical Research Lab
Medical Library, Naval Submarine Base
Box 900
Groton, CT 06340 (1)

Director
Naval Biosciences Laboratory
Naval Supply Center, Bldg 844
Oakland, CA 94625 (1)

Naval Air Systems Command
ATTN: V/STOL Aircraft Branch
Department of the Navy
Washington, DC 20360 (1)

US Navy
Naval Research Laboratory Library
Code 1433
Washington, DC 20375 (1)

US Navy
Naval Air Development Center
Technical Information Division
Technical Support Department
Warminster, PA 18974 (1)

Human Factors Engineering Division
Aircraft & Crew Systems Technology Directorate
Naval Air Development Center
Warminster, PA 18974 (1)

US Navy
Naval Research Laboratory Library
Shock & Vibration Information Center
Code 8404
Washington, DC 20375 (1)

Dir of Biol & Med Sciences Div
Office of Naval Research
800 N. Quincy Street
Arlington, VA 22217 (1)

CO, Naval Medical R&D Command
National Naval Medical Center
Bethesda, MD 20014 (1)

Commander
Naval Aeromedical Research Laboratory Det.
PO Box 29407
Michoud Station
New Orleans, LA 70129 (1)

Federal Aviation Administration
Office of Aviation Medicine
Civil Aeromedical Institute
ATTN: Library
Oklahoma City, OK 73101 (1)

Department of Defence
R.A.N. Research Laboratory
P.O. Box 706
Darlinghurst, N.S.W. 2010
Australia (1)

MAJ J. Soutendam
DCIEM/SOAM
1133 Sheppard Avenue West
P.O. Box 2000
Downsview, Ontario
M3M 3B9 (1)

Canadian Society of Avn Med
c/o Academy of Medicine, Toronto
ATTN: Ms Carmen King
288 Bloor Street West
Toronto, Ontario
M55 1V8 (1)